State of California

The Resources Agency

Department of Water Resources

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Special Report

for the XXVI

Border Governors

Conference

water & border area climate change

AN INTRODUCTION

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Department of Water Resources
P.O Box 942836
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Foreword

Incorporation of climate change into water resources planning and management is important for California and for the U.S. — Mexico border region. This report was prepared for the XXVI Border Governors Conference to provide an introduction to climate change in the border region from the water sector perspective. The border region is arid, and vulnerable to water resources impacts of climate change. Expected effects of human-induced climate change will result in increased warming and drying of the southwestern U.S. and northwestern Mexico, exacerbating competition for the region's finite water resources. The border region's aridity and geographic vulnerability to climate change impacts emphasize the need for examining water supply reliability and for developing collaborative drought preparedness and climate change adaptation tools.

Lester A. Snow
Director, Department of Water Resources

Photo courtesy of USGS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

climate change
in the Global Perspective

CHAPTER 1

Photo courtesy of Connie Woodhouse, University of Arizona

Introduction

The United States – Mexico border region is noted for its aridity. Drought is a commonplace event, and a recurring aspect of natural climate variability.

The expected effects of human-induced climate change will result in increased warming and drying of the southwestern U.S. and northwestern Mexico, exacerbating competition for the region's finite water resources. The warming and drying will be occurring at the same time that the region faces significant population growth, desires for new economic development and for environmental preservation, and needs for upgraded and enhanced water infrastructure.

This report summarizes the border region's hydrologic setting, focusing especially on the international rivers — the Colorado and Rio Grande — that are major sources of developed water supplies; discusses expected impacts of climate change on water resources; and describes adaptation strategies. Preparation of the report was initiated in response to discussion of drought and climate change in the U.S.-Mexico Border Governors' Conference worktables, and to an increasing level of engagement in transboundary water management discussions regarding the region's major water sources.

The border region's aridity and geographic vulnerability to climate change impacts emphasize the need for examining water supply reliability and for developing collaborative drought preparedness and climate change adaptation tools. As a first step to understanding regional climate change impacts, the Department convened a border-area climate change science workshop at the University of Arizona in April 2008 (see sidebar). The results of that workshop have been used to help prepare this report, and graphics provided by the participants are included herein.

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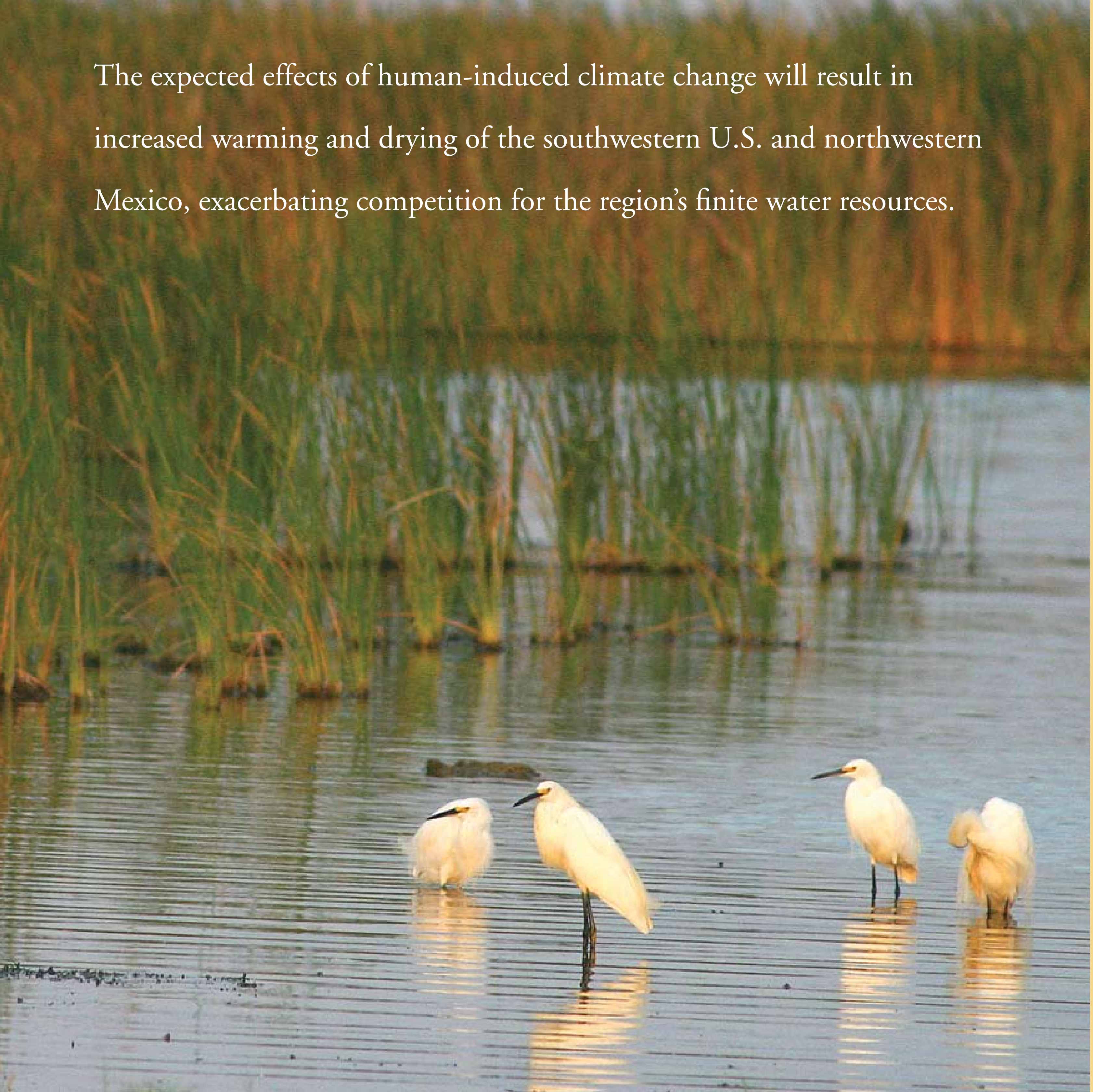

SPECIAL ACKNOWLEDGEMENTS

The California Department of Water Resources (CDWR) co-sponsored a science workshop on border-area climate change with the Arizona Water Institute in April 2008, with workshop arrangements being facilitated by the University of Arizona's Climate Assessment for the Southwest (CLIMAS). A particular focus of the workshop was on the Colorado River and Rio Grande Basins, which provide much of the region's surface water supplies. CDWR appreciates the information contributed by workshop participants for preparation of this report, and would like to recognize the participants:

Christopher Castro, *University of Arizona*

Plácido dos Santos, *Arizona Water Institute*

Daniel Ferguson, *CLIMAS*

Gregg Garfin, *CLIMAS*

Brian Hurd, *New Mexico State University*

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Andrea Ray, *National Oceanic and Atmospheric Administration*

Joellen Russell, *University of Arizona*

Christopher Scott, *University of Arizona*

Linda Stitzer, *Arizona Department of Water Resources*

Robert Varady, *University of Arizona*

Margaret Wilder, *University of Arizona*

Connie Woodhouse, *University of Arizona*

CDWR also thanks Gregg Garfin for his review of this report, and expresses its appreciation for the assistance provided by CLIMAS.

Photo courtesy of Sonoran Institute

Climate Change – Global Overview

Summer precipitation is an important component of total annual precipitation in parts of the border region. The North American Monsoon Experiment (NAME), a science research program, has been seeking to understand processes affecting monsoon formation and prediction. To support this work, NAME proposes installation of a regional climate observing system having instrumentation in the Gulf of California and Sonora.

The Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report in 2007, making a strong statement regarding human-induced climate change and its effects.

The IPCC is an intergovernmental entity, established by the World Meteorological Organization and the United Nations Environment Programme, which began its assessments of climate change with an initial report published in 1990. The Fourth Assessment Report (*Climate Change 2007: Synthesis Report*) emphasized that the effects of climate change are already visible in the measured record ***(Figure 1)***, and noted that:

- *Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.*
- *The understanding of anthropogenic warming and cooling influences on climate has improved since the TAR (Third Assessment Report), leading to very high confidence that the global average net effect of human activities since 1750 has been one of warming…*
- *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.*
- *At continental, regional and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones.*
- *Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas emissions.…Discernable human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.*
- *Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilised.*

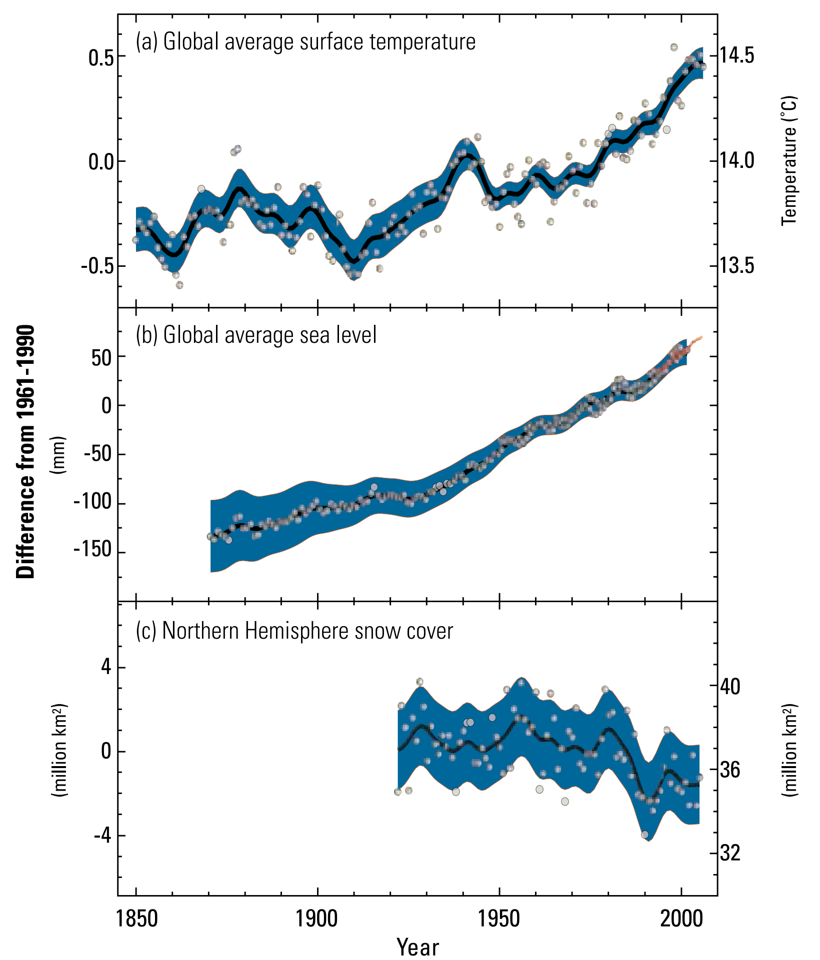


FIGURE 1

Changes in Temperature, Sea Level and Northern Hemisphere Snow Cover

Observed changes in:

(a) Global average surface temperature;

(b) Global average sea level from tide gauge (blue) and satellite (red) data;

(c) Northern Hemisphere snow cover for March-April.

All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c).

Source: IPCC Fourth Assessment, Synthesis Report, Figure 1.1

Climate change is expected to increase the frequency and severity of droughts in the U.S. Southwest/Mexican Northwest, creating management challenges for river basins such as the Rio Grande.

Of particular interest to water agencies, IPCC's *Climate Change 2007: Synthesis Report* also noted that *the type, frequency and intensity of extreme events are expected to change as Earth's climate changes, and these changes could occur even with relatively small mean climate changes. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events.* The report goes on to say that *wet extremes are projected to become more severe in many areas where mean precipitation is expected to increase, and dry extremes are projected to become more severe in areas where mean precipitation is projected to decrease.* ***Figure 2*** illustrates modeled changes in hydrologic variables at a global scale Some of the report's other findings with respect to projected climate changes include:

- *All of North America is very likely to warm during this century… In northern regions, warming is likely to be largest in the winter, and in the southwest USA largest in the summer.*
- *Annual mean precipitation is likely to decrease in the southwest USA.*
- *Snow season length and snow depth are very likely to decrease in most of North America.…*

Precipitation decreases attributed to climate change are expected to occur in the border region, where continuing population growth has been the norm. Although policy-makers at the state and federal levels are increasingly focusing on strategies for mitigating climate change effects — through actions such as formation of the Western Climate Initiative in the U.S. or adoption of the National Strategy on Climate Change in Mexico — the scientific expectation that climate warming would continue for centuries even if greenhouse gas emissions were immediately controlled points to the need for long-term sustainable management of border-area water resources.

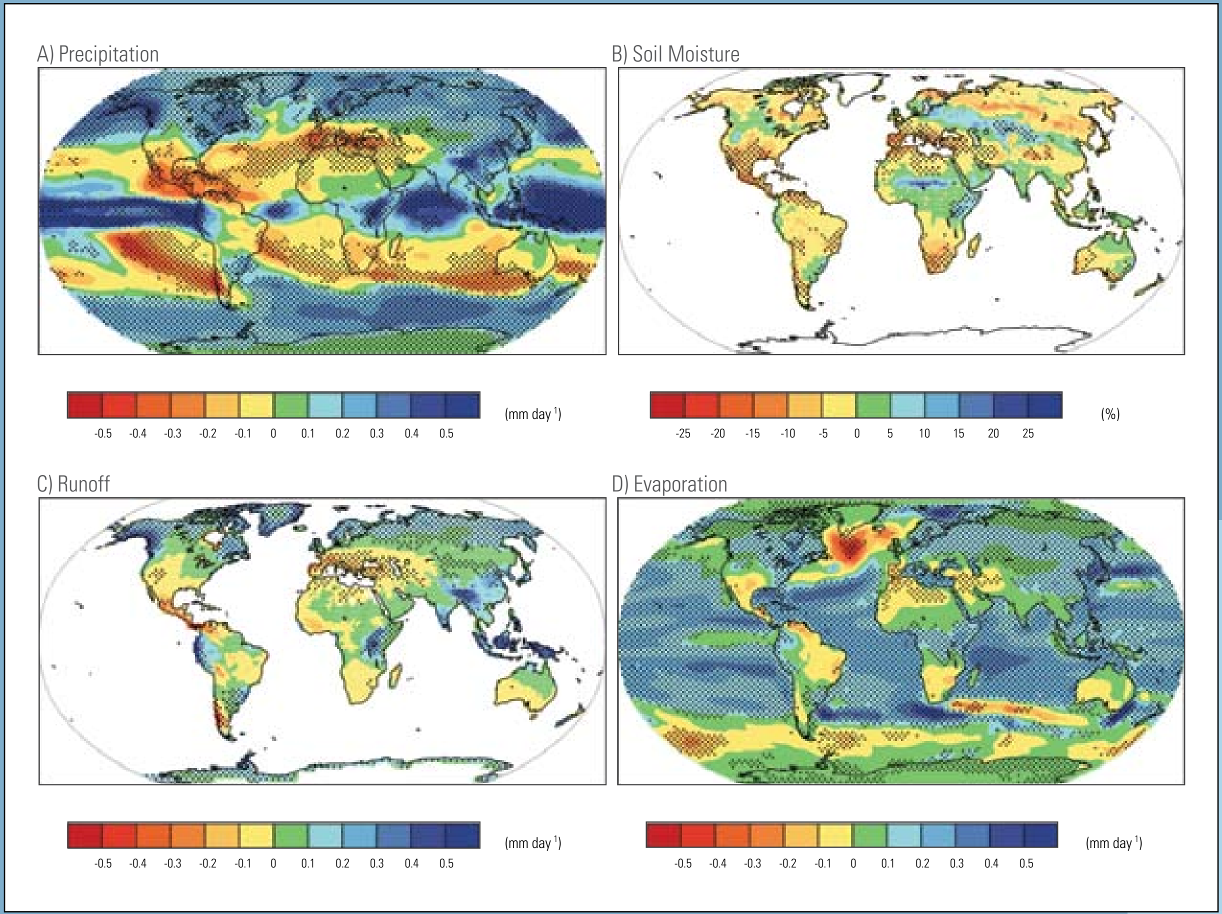


FIGURE 2

Modeled Changes in Hydrologic Variables

Multi-model mean changes in:

(a) precipitation (mm day -1),

(b) soil moisture content (%),

(c) runoff (mm day -1) and

(d) evaporation (mm day -1).

To indicate consistency in the sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change. Changes are annual means for the SRES A1B scenario for the period 2080 to 2099 relative to 1980 to 1999. Soil moisture and runoff changes are shown at land points with valid data from at least 10 models.

Source: IPCC Fourth Assessment, Working Group 1 Report, Figure 10.12

California Climate Change Mitigation and Adaptation

Governor's Executive Order S-3-05 in June 2005 recognized that: *mitigation efforts will be necessary to reduce greenhouse gas emissions and adaptation efforts will be necessary to prepare Californians for the consequences of global warming.*

The order established emission reduction targets and called for biannual preparation of mitigation and adaptation plans to respond to climate change impacts, including impacts to water supply, public health, agriculture, the coastline, and forestry. Subsequently, the California Global Warming Solutions Act of 2006 (Statutes of 2006, Chapter 488) required development of regulations and market mechanisms to reduce California's greenhouse gas emissions by 25 percent by 2020. California has further signed agreements with other states and nations to cooperate in the reporting and management of greenhouse gas emissions and development of clean energy sources.

California's Climate Action Team (CAT), a group of state agencies formed in response to the Governor's Executive Order, produced its first biannual report on adaptation in 2006. With respect to the water sector, the report found that:

- *By the 2035–2064 period, snowpack in the Sierra Nevada could decrease 10 to 40 percent depending on the amount of warming and precipitation patterns. By the end of century, snowpack could decrease by as much as 90 percent if temperatures rise to the higher warming range, almost double the loss is expected if temperature rises stay within the lower warming range.*

- *Flows into the major Sierra Nevada reservoirs could decline between 25 to 30 percent if temperatures rise to the medium warming range and precipitation decreases by approximately 20%.*

- *… historical coastal structure design criteria may be exceeded, the duration of events will increase, and these events will become increasingly frequent as sea level rise continues. On the open coast, impacts during these events will continue to be exacerbated by high surf from wind, waves, and, in the Sacramento/San Joaquin Delta of the San Francisco Bay estuary, by floods that may further jeopardize levees and other structures.*

The global climate models and emissions scenarios used to examine water resources impacts in California's 2006 initial report on adaptation yielded temperature rise (2000 to 2100) projections from approximately 1.7˚C to 3.0˚C (3.0˚F-5.4˚F) in the lower range of projected warming, 3.1˚C-4.3˚C (5.5˚F-7.8˚F) in the medium range, and 4.4˚C to 5.8˚C (8.0˚F-10.4˚F) in the higher range. To put these figures into perspective, the upper range of projected warming is greater than the annual mean temperature difference between San Francisco and San Jose.

Mexico's National Strategy on Climate Change

In 2007, Mexico's Comisión Intersecretarial de Cambio Climático released its *Estrategia Nacional de Cambio Climático*.

The national strategy detailed proposed greenhouse gas mitigation measures in the energy, forestry, and land use sectors, and described the basis for a national approach to adaptation. The strategy identified adaptation priorities, including:

- Review the institutional structure for risk management associated with hydro-meteorological threats.
- Design and implement a climate modeling program as part of a national climate information system.
- Promote actions to reduce vulnerability and diminish risk in local, state, and regional development plans.

The strategy also called for research and adaptation capacity-building in areas such as water resources management and hydro-meteorological risk management, and coastal management. Some specific areas of emphasis or challenges were:

- Design a program promoting aquifer recharge.
- Adjust water treatment technology to changed climate conditions.
- Plan for an increase of 40 centimeters in mean sea level by the end of the century, for coastal infrastructure development.
- Develop seasonal climate forecasts and regional scenarios.

CHAPTER 2

water in the Border Region

CHAPTER 2

Background and Setting

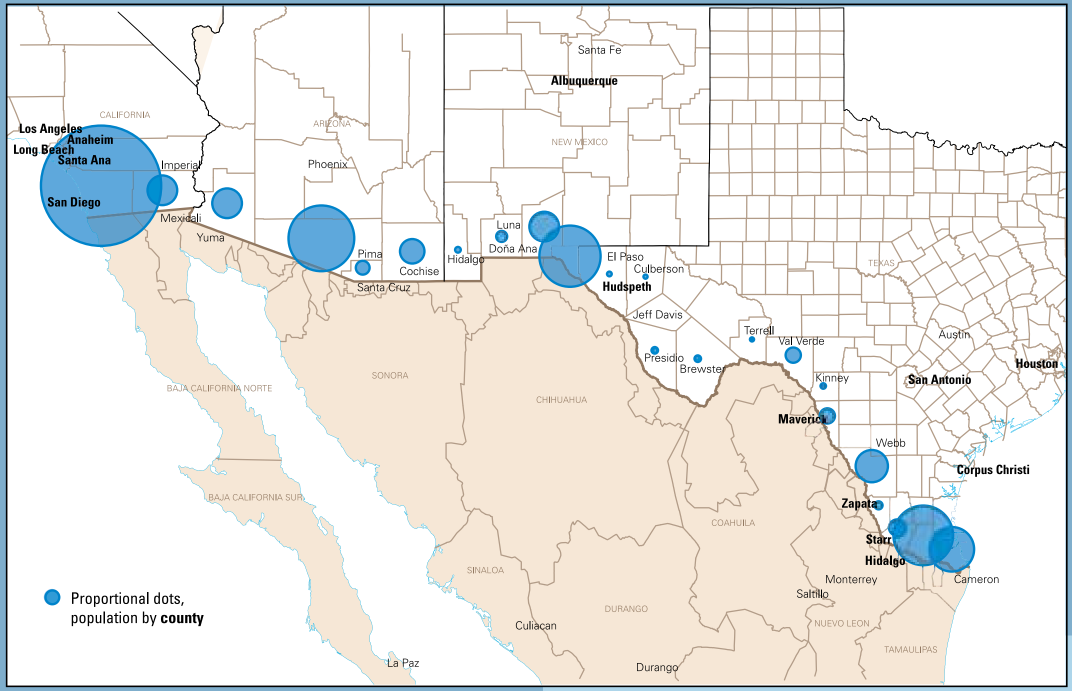
Stretching 1,954 miles (according to the International Boundary and Water Commission) from the Pacific Ocean to the Gulf of Mexico, the international boundary spans four states on the U.S. side and six on the Mexican side *(Figure 3)*. As indicated in ***Table 1***, most of the border states are expected to experience significant population growth in the coming decades. ***Table 2*** shows recent population information for selected border region municipalities and municipalities relying on the major international rivers. According to the Border Environment Cooperation Commission (BECC), about 90 percent of the border population is contained in fourteen paired trans-border communities. ***Figure 4*** shows the concentration of population along the border. For Mexico especially, the border region is an important contributor to its national economy *(Figure 5)*, although it is the driest part of the nation *(Figure 6)*.

Arid and semi-arid conditions characterize much of the border area. The northwestern part of the area (coastal California) is characterized by a Mediterranean climate with moderate, rainy winters and hot, dry summers. To the east, an area of high pressure develops in the summertime over the Four Corners area, creating a wind pattern that brings in moisture from the Gulf of California, Gulf of Mexico, and tropical Pacific, creating the North American monsoon. ***Figure 7*** shows the relative importance of summer precipitation in areas affected by the monsoon. Local rainfall, however, directly serves only part of border-area water needs. Major sources of water supply are the Colorado River and Rio Grande systems, and groundwater. The international Colorado River and the Rio Grande basins are the major basins of the U.S. southwest/Mexican northwest. Other much smaller international rivers include the Tijuana River, New River, San Pedro River, and Santa Cruz River. Runoff in both the Colorado River and Rio Grande Basins is snowmelt-driven, with a relatively small portion of the basins' upper watersheds contributing the majority of system runoff. The Colorado is by far the larger of the two rivers in terms of flow volume.

FIGURE 3

Border Region Location Map

…most of the border states are expected to experience significant population growth in the coming decades. According to the Border Environment Cooperation Commission (BECC), about 90 percent of the border population is contained in fourteen paired trans-border communities.



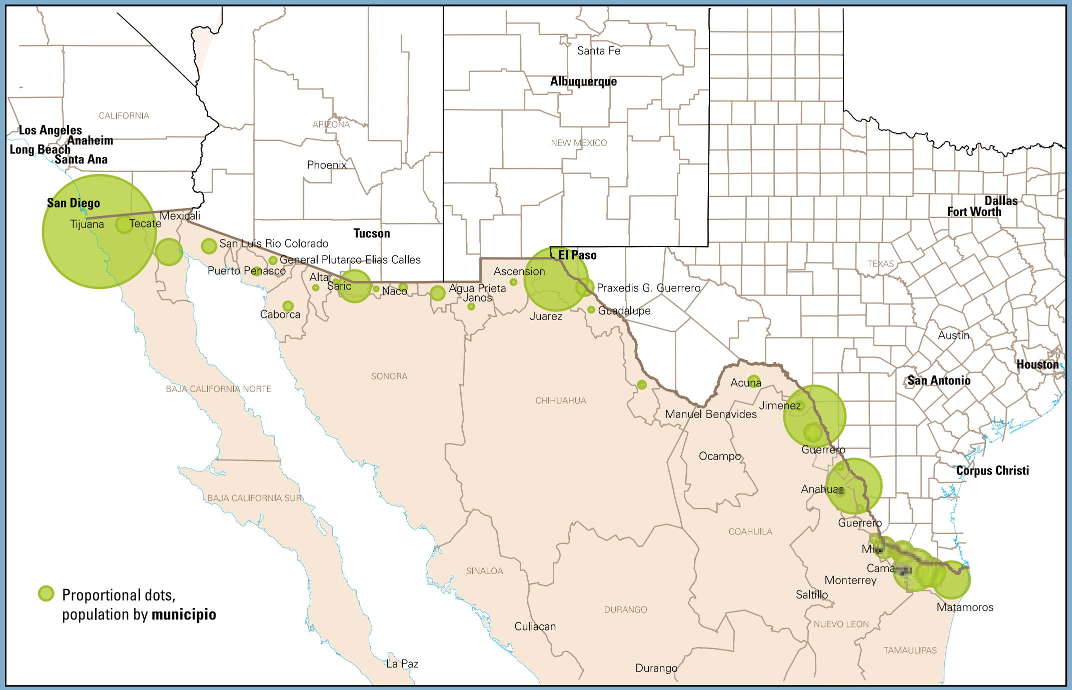


FIGURE 4

Population Density by County/Municipio in 2004

Source: US / Mexico Border Counties Coalition "At the Cross Roads: US / Mexico Border Counties in Transition"

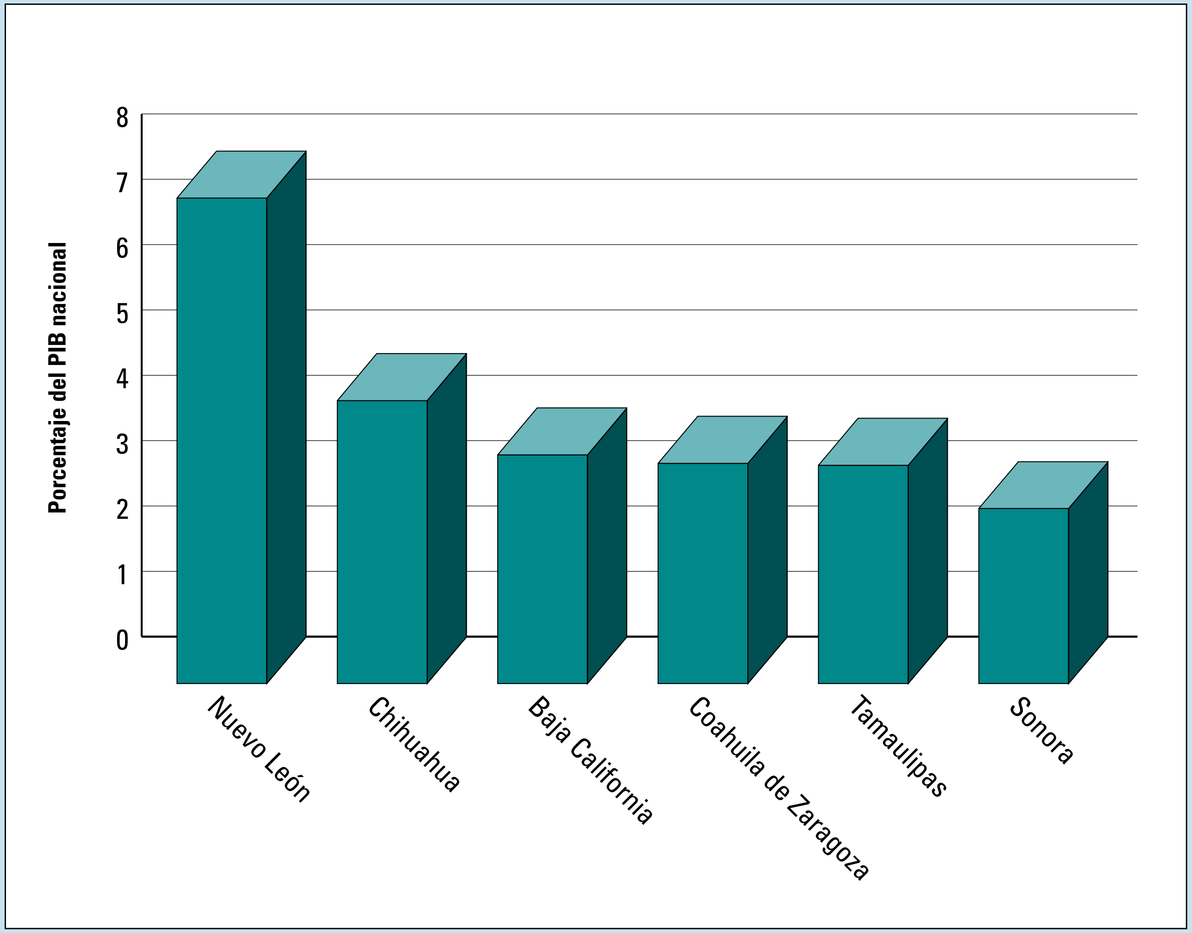


FIGURE 5

Percent of Gross Domestic Product by State

Source: CNA, 2007

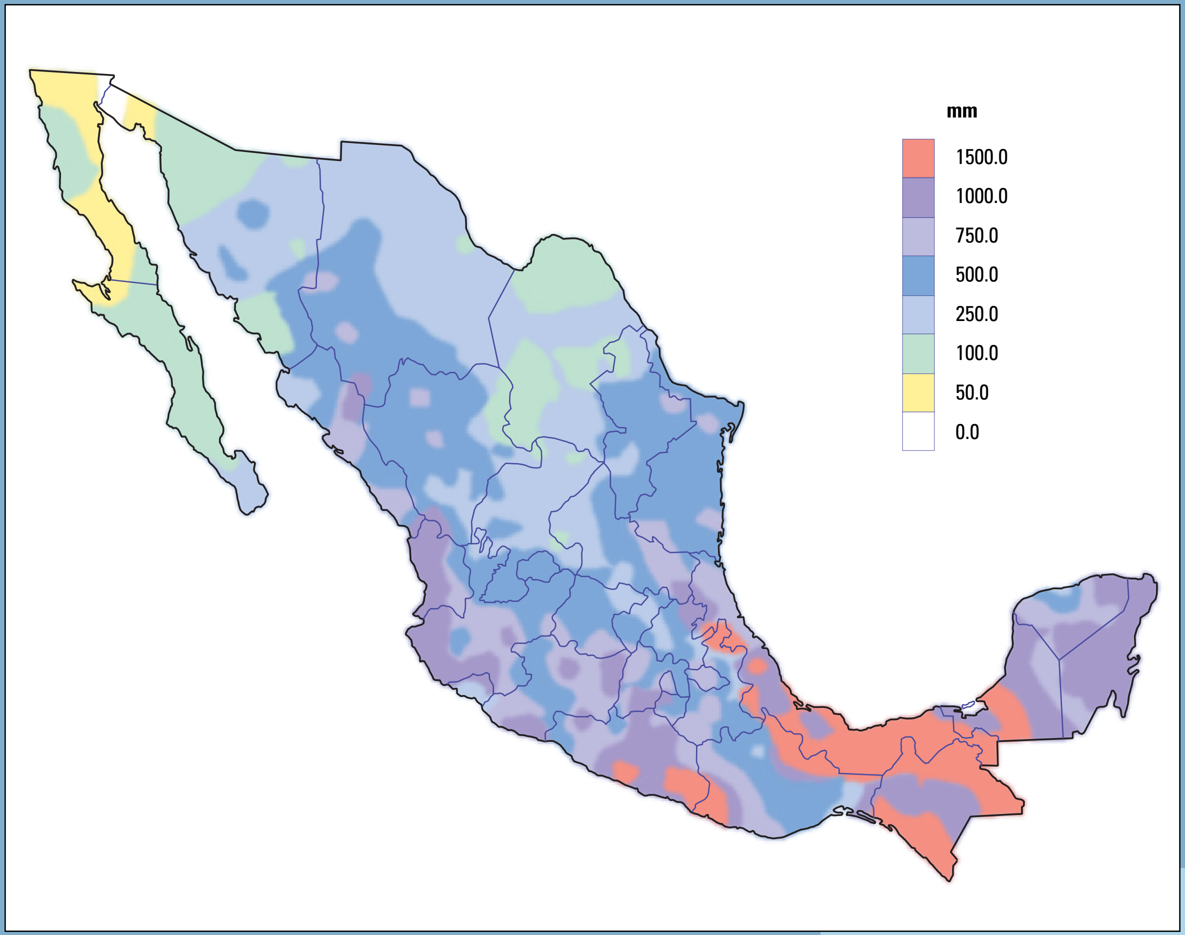


FIGURE 6

The border region is an important contributor to Mexico's national economy, although it is the driest part of the nation…

Mexico Annual Precipitation, 2006
(Millimeters)

Source: CNA, 2007

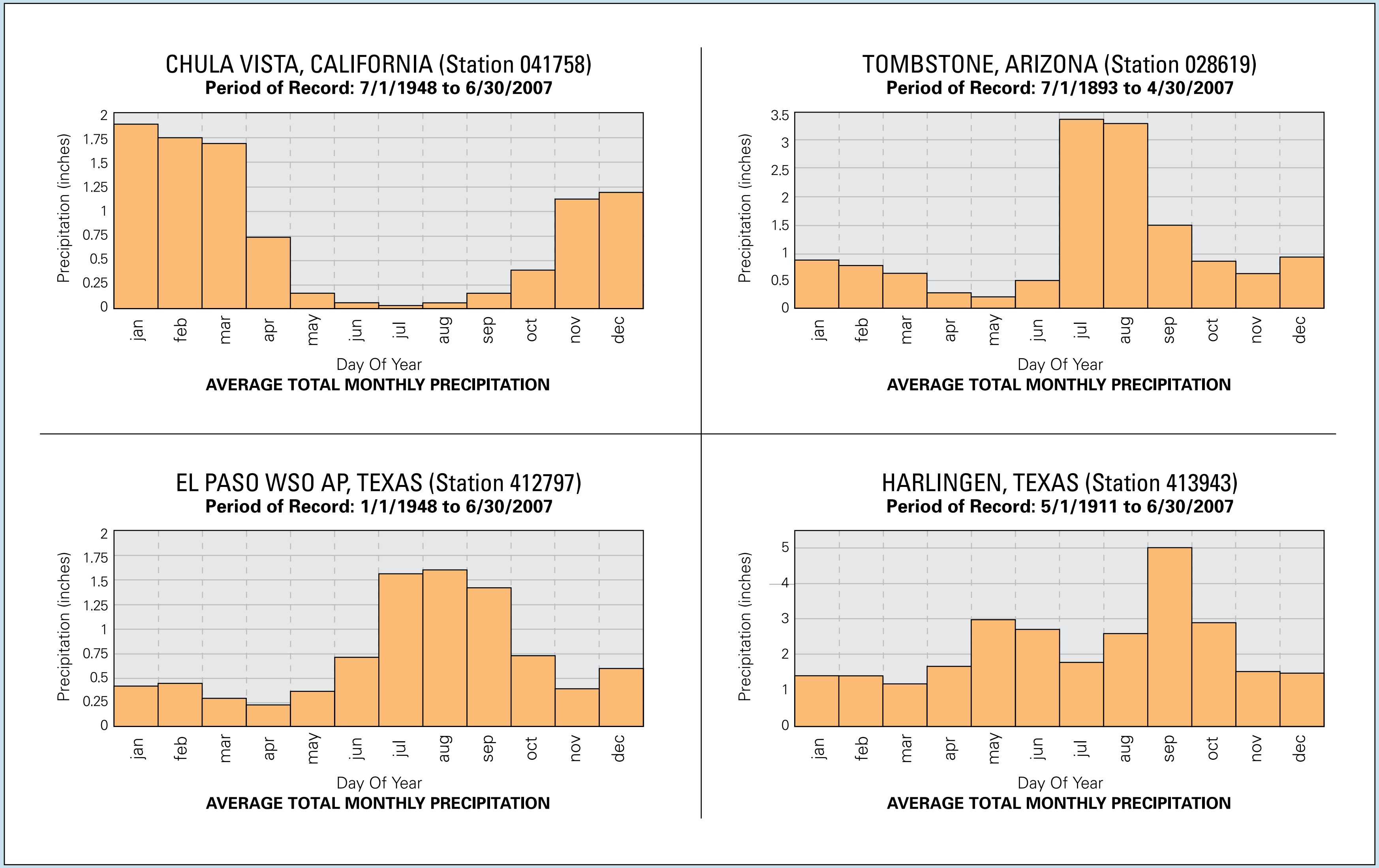


FIGURE 7

Seasonality of Precipitation Example

Data Source: Western Regional Climate Center, compilation by Gregg Garfin, University of Arizona

Table 1 indicates that most of the border states are expected to experience significant population growth in the coming decades. Table 2 shows recent population information for selected border region municipalities and municipalities relying on the major international rivers.

Border State Population Estimates and Projections (millions)

STATE	2005 ESTIMATE	2030 PROJECTION
California	36.1	46.4
Arizona	5.9	10.7
New Mexico	1.9	2.1
Texas	22.9	33.3
Baja California	2.8	5.1
Sonora	3.3	3.8
Chihuahua	2.5	3.1
Coahuila	4.2	5.4
Nuevo León	2.4	2.8
Tamaulipas	3.0	3.8

TABLE 1 - Source: U.S. Census Bureau and Consejo Nacional de Población

2005 Population Estimates (millions), Selected Municipalities

MUNICIPALITY	2005 ESTIMATE
San Diego	2.9
Las Vegas	1.7
Phoenix	3.9
El Paso	0.72
Tijuana	1.4
Mexicali	0.85
Ciudad Juárez	1.3

TABLE 2 - Source: U.S. Census Bureau and Consejo Nacional de Población U.S. figures are for metropolitan statistical areas

Water Supplies

The Colorado River has its headwaters in Wyoming's Green River Basin and traverses parts of seven U.S. states before entering Mexico and terminating in the Gulf of California. For purposes of administration, it is divided into an Upper Basin and Lower Basin at Lee Ferry, just upstream of Lake Powell. The river basin is highly snowmelt dominated, with about 15 percent of the watershed in the high-elevation headwaters area in Wyoming and Colorado contributing about 85 percent of the river's average annual unimpaired flow of about 15 million acre-feet (MAF). Nearly 60 MAF of reservoir storage capacity has been developed on the mainstem and tributaries. The two largest reservoirs are the 24 MAF Lake Powell in the Upper Basin and the 26 MAF Lake Mead in the Lower Basin.

Rights to use of Colorado River water are governed by an extensive and complex legal framework that includes interstate compacts, federal and state legislation, court decrees, and an international treaty. *Table 3* summarizes the basic allocation of Colorado River water.

Annual Apportionment of Use of Colorado River Water

(million acre-feet of consumptive use)

Upper Basin States (Wyoming, Colorado, Utah, New Mexico, small portion of Arizona)	7.5
Lower Basin States (California, Arizona, Nevada)	7.5
California	4.4
Arizona	2.8
Nevada	0.3
Mexico	1.5

TABLE 3 - Notes: 1. The Lower Basin States further share an apportionment of 1 MAF of surplus water, when available. 2. Mexico's apportionment includes 200 thousand acre-feet (200 TAF) of surplus water, when available. Deliveries to Mexico must meet specified salinity requirements.

Low reservoir levels at Lake Mead reflect persistent drought in the basin.

The 1944 Treaty

The 1944 Treaty for the "Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande" allocated waters of the Colorado River and of the Rio Grande between the two nations, and provided for construction of works such as diversion structures and dams (i.e. Amistad and Falcon Dams on the Rio Grande) necessary to effectuate the allocations. The Treaty also called for preparation of studies on allocation and management of the Tijuana River, and for studies and implementation of flood control works on the international reach of the Rio Grande (from Fort Quitman to the Gulf of Mexico). The Treaty is administered by the U.S. and Mexican Sections of the International Boundary and Water Commission (IBWC), who are jointly responsible for operation and maintenance of the international facilities.

The eight-year period from water years 2000 through 2007 was a period of unprecedented dryness in the Colorado River Basin when compared to the roughly 100-year historical period of measured hydrology. Colorado River water users in the U. S. and Mexico did not experience reduced deliveries during this time thanks to the basin's large storage capacity. Total reservoir system storage in the Basin dropped to as low as 52 percent of capacity in 2004; total system storage at the end of water year 2007 was 54 percent of capacity. The prospect of shortages due to drought becomes increasingly likely in the future as demands on the river system increase, as demonstrated by recent U.S. Bureau of Reclamation (USBR) modeling ***(Figure 8)*** for first-ever shortage criteria for reservoir operations. As indicated in the figure, all of the alternatives that USBR examined its Environmental Impact Statement (EIS) show a probability of shortages of some magnitude in the future.

The Rio Grande has its headwaters in the San Juan Mountains of southern Colorado, flows through New Mexico, forms the international boundary between Texas and Mexico, and terminates in the Gulf of Mexico. The watershed area is divided roughly equally between the U.S. and Mexico. The Upper Rio Grande Basin is defined as the headwaters area in Colorado downstream to Fort Quitman, Texas, (about 60 miles downstream from El Paso). The Lower Rio Grande Basin, from Fort Quitman to the Gulf, takes in the river's largest tributaries — such as the Pecos River and Devil's River in Texas and the Rio Conchos, Rio Salado, and Rio San Juan in Mexico.

There are only two large reservoirs on the upper Rio Grande mainstem, both in New Mexico — USBR's Elephant Butte and Caballo Reservoirs. (Additionally, the upper Rio Grande receives a transbasin diversion from the Upper Colorado River basin via USBR's San Juan-Chama project, a diversion that amounts to about 94 TAF annually.) The lower Rio Grande has two international storage reservoirs on the mainstem -- Amistad and Falcon. Most of the other storage in the lower Rio Grande is on Mexican tributaries such as the Rio Conchos. Overall, about half of the basin's 18 MAF of storage is in Mexico, with the other half being in the U.S. and on the international reach of the mainstem. The upper and lower river basins are relatively hydraulically disconnected. Runoff in the upper basin (average annual flow of about 1.1 MAF at the Compact accounting point of the Otowi gage in New Mexico) is largely used within that basin. Mainstem flow in the lower river is dominated by flow from Mexican tributaries, particularly the Rio Conchos, which has its headwaters in the Sierra Madre Occidental in Chihuahua.

USBR's 2 MAF Elephant Butte Reservoir on the Upper Rio Grande is the largest reservoir in New Mexico.

Photo courtesy of USBR

Involuntary and Voluntary Lower Basin Shortages, Comparison of Action Alternatives to No Action Alternative

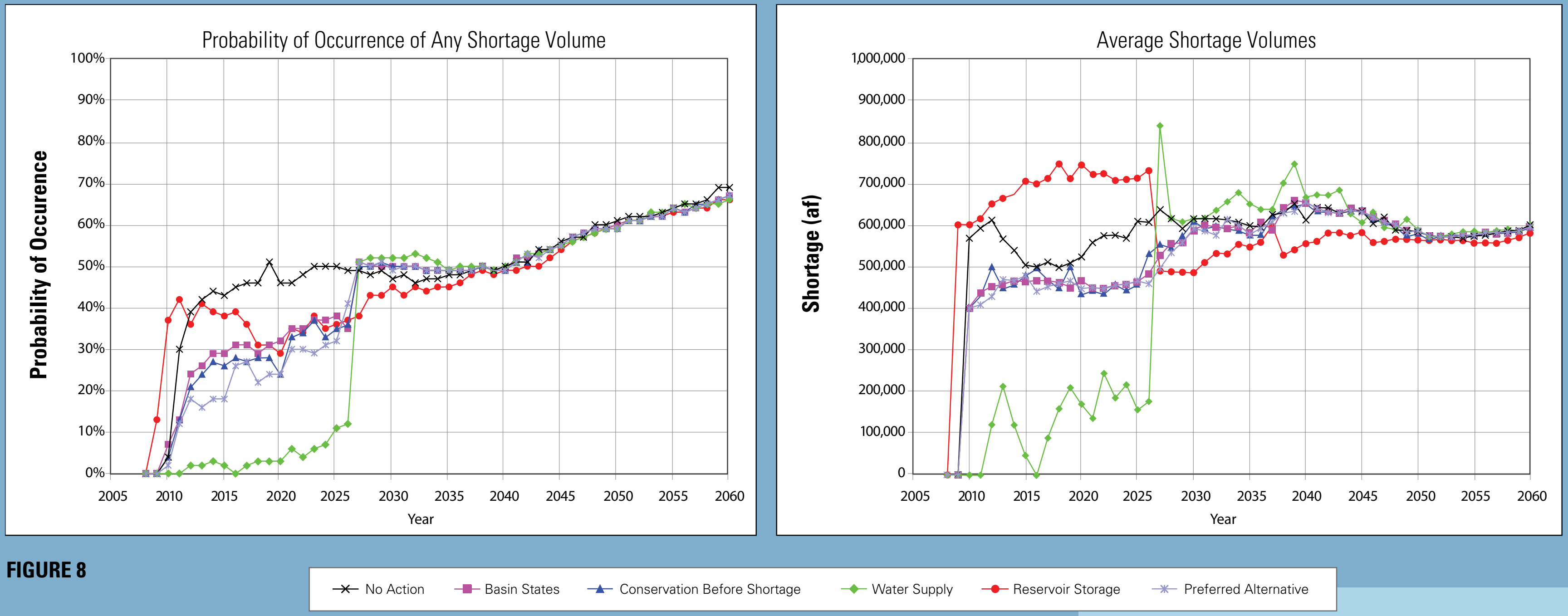


FIGURE 8

Probability of Future Lower Colorado River Basin Shortages

Source: USBR 2007 Final Environmental Impact Statement, Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead, 2007

The estimated cost of El Paso's new reverse osmosis plant for treating brackish groundwater was about $95 million.

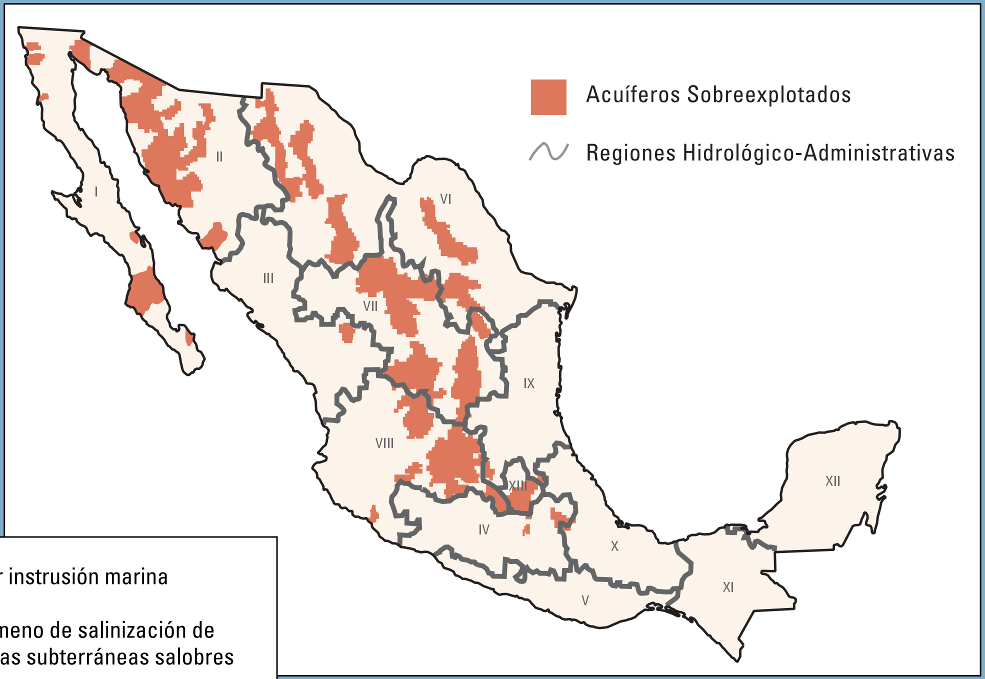
Waters of the Upper Rio Grande are divided by a 1938 interstate compact among Colorado, New Mexico, and Texas. On the international reach of the river, two treaties between the U.S. and Mexico apply. Above Fort Quitman, the Convention of 1906 requires the U.S. to annually deliver 60 TAF of Rio Grande water to Mexico at Ciudad Juárez. Below Fort Quitman, the 1944 Water Treaty divides the flow of the river and of specified tributaries in varying percentages between the two nations. The only specific quantity of water identified in that Treaty is associated with a requirement that one-third of the flow reaching the main channel from specified Mexican tributaries (including the Rio Conchos), but not less than an average of 350 TAF annually in a five consecutive year cycle, be allocated to the U.S.

Photo courtesy of CDM

The Rio Grande system experienced an extended drought period in the late 1990s/early 2000s. With respect to drought on the Rio Grande, the border Governors adopted the following joint declaration at their 2007 Border Governors Conference:

Work with the goal of obtaining by December 2009 (depending on ongoing efforts), a definition of the criteria by which a condition of drought and extraordinary drought would be identified in the Rio Grande Basin as specified in Section II of the 1944 Water Treaty. The definition should facilitate, even under adverse climatic effects, the understanding and the implementation of the international agreements regarding water. The proposal will be submitted to the federal governments of both nations for their consideration.

Groundwater is also an important resource in the border area. Transboundary aquifers range in importance from small basins with minimal extractions to a few large basins of special note, such as the Hueco Bolson and Mesilla Bolson (shared among New Mexico, Texas, and Mexico) that are major sources of supply for urbanized areas. On Mexico's side of the border, aquifers that are overdrafted or have water quality (salinity) management challenges are identified in ***Figure 9***. Similar management challenges are present in the U.S. The City of El Paso, for example, has just completed construction of a 27.5 MGD brackish groundwater desalination plant to make use of the extensive volume of brackish groundwater in the Hueco Bolson.



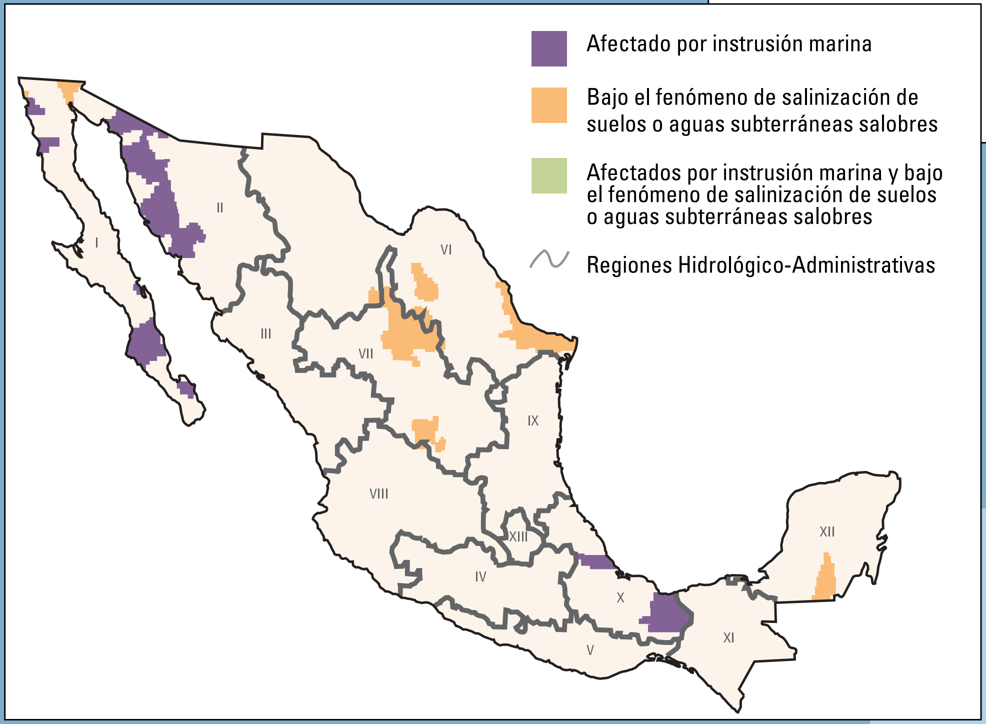


FIGURE 9

Aquifers Identified by Mexico as Having Overdraft or Salinity Challenges

Source: CNA, 2007

Water Uses

An extensive system of water infrastructure has been constructed — especially in the Colorado River Basin — to convey water from the major river systems to areas where it is needed. ***Table 4*** lists some of the largest conveyance facilities. Throughout the region, agriculture is the dominant water using sector. ***Figure 10*** shows as an example the relative breakdown of water use by type for the Mexican border states. Urban water demands are expected to constitute an increasing share of total water use as the region's population continues to grow, illustrated for Texas' Rio Grande planning region by ***Figure 11***, taken from the 2007 Texas state water plan. Water conservation and improved agricultural water use and management efficiencies are expected to be important components of meeting future water needs in the border region. Reflecting the importance of water use efficiency improvements, the border Governors adopted the following joint declaration at their 2007 Border Governors Conference:

Continue working with the Border Environment Cooperation Commission, the North American Development Bank, the Bureau of Reclamation, and other entities with available funds to finance improvements to the infrastructure of water conveyance systems, including financing for the identification, development, and construction of projects for all water use sectors....

Improvements to existing border water infrastructure will play an important part in helping meet future water needs in the region. Present urban needs in the Tijuana metropolitan area, for example, are taxing the capacity of Mexico's Tijuana aqueduct from the Colorado River. IBWC's Minute 287, adopted in 1992, provided for emergency deliveries of a portion of Mexico's Colorado River allocation to Tijuana via U.S. infrastructure at times when Tijuana Aqueduct capacity was unavailable. Adoption of an updated minute on this subject is presently under consideration.

According to U.S./Mexico Border Counties Coalition information for the U.S. side of the border, New Mexico's agricultural economy is the one most greatly influenced by the contribution from border-area agriculture (Figure 12).

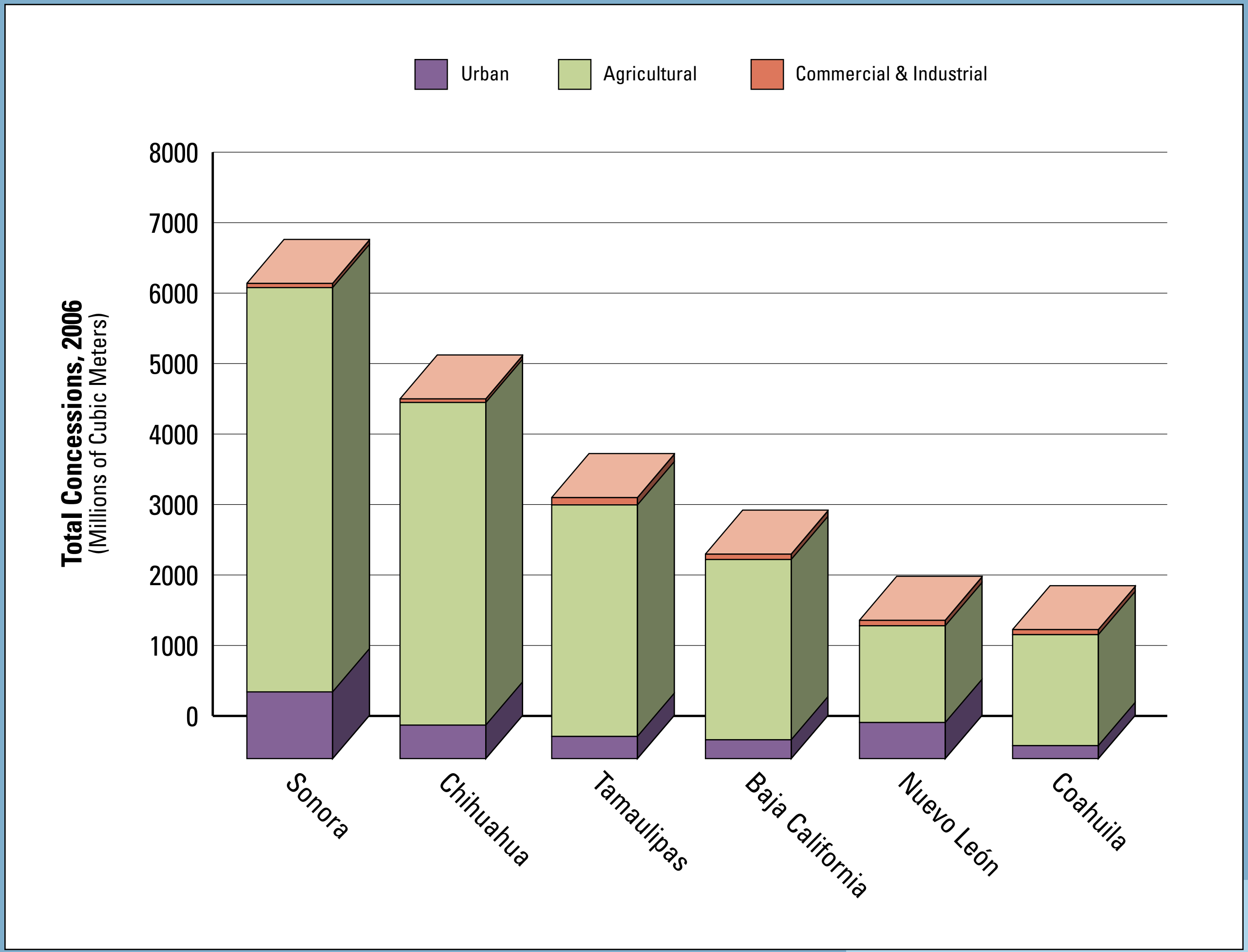


FIGURE 10

Volumes of Water Under Concessions, by Type of Use

Note: Does not include water use for power generation.

Source: CNA, 2007

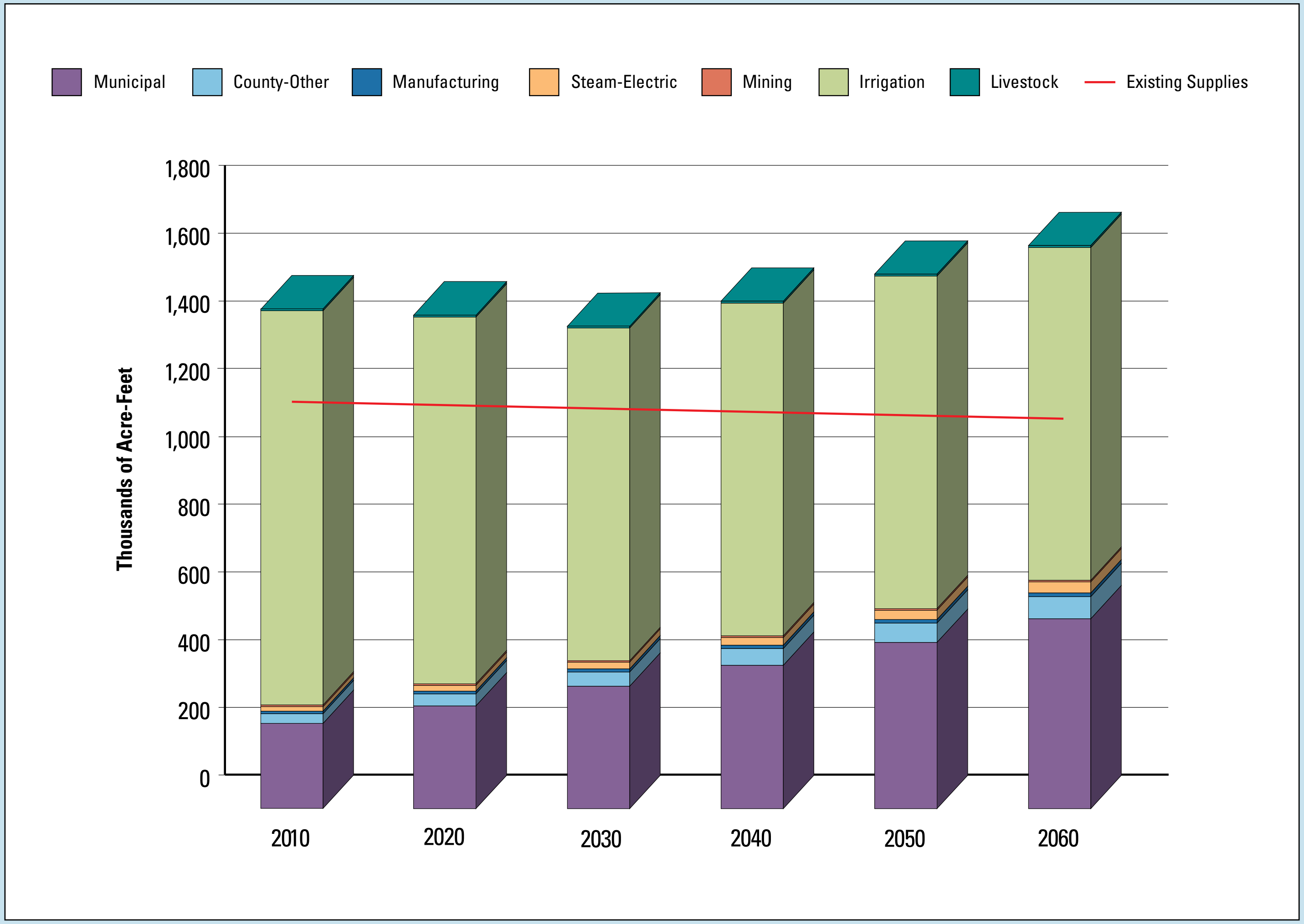


FIGURE 11

Projected Water Demands, Texas' Rio Grande Planning Region

Projected total water demand and existing water supplies for 2010-2060.

Source: Texas State Water Plan, 2007

2003 Percentage of Cash Receipts, Crops in Each State and Border Counties

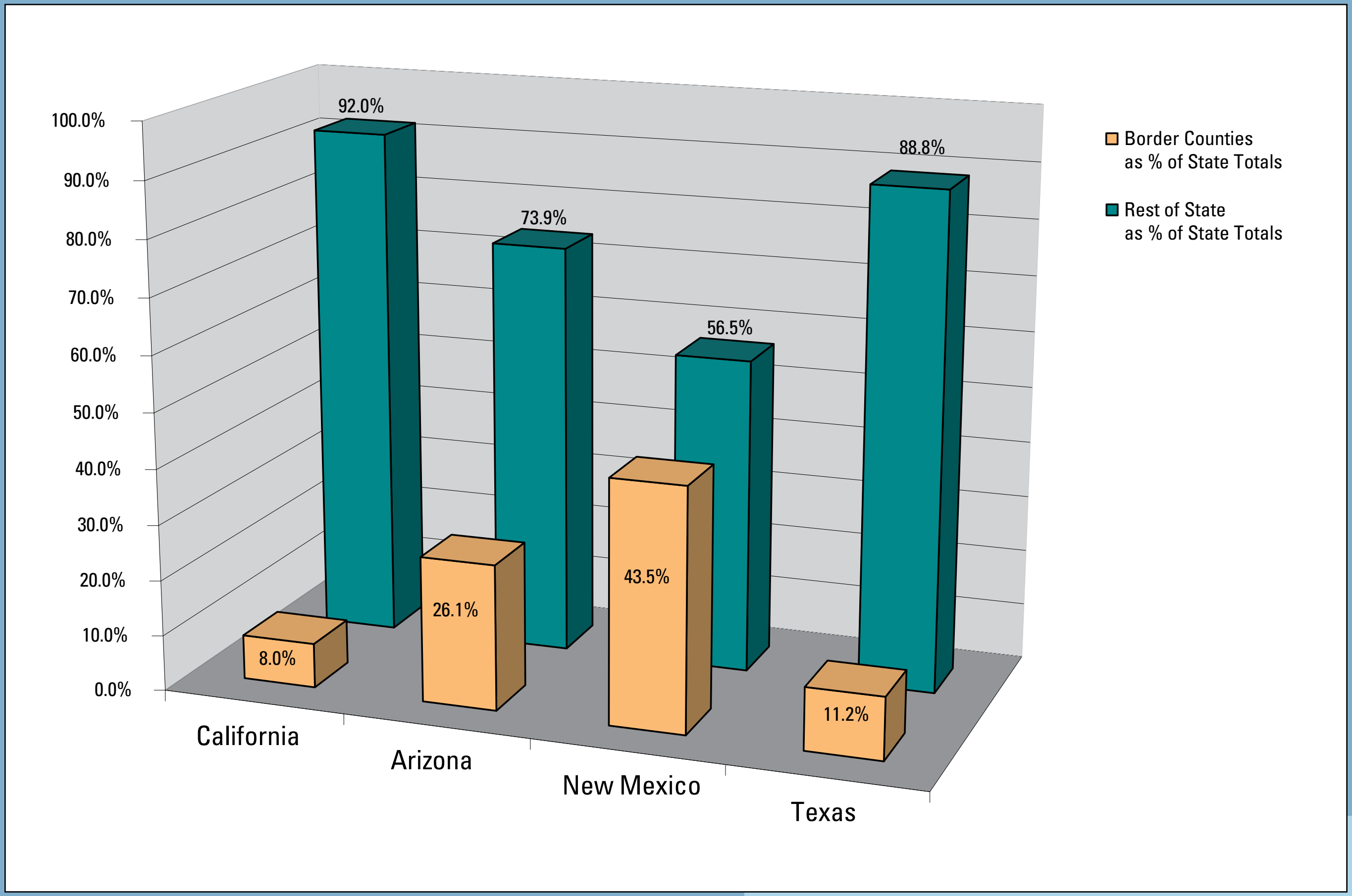


FIGURE 12

Contribution of Border Agriculture to Total State Agricultural Receipts, U.S. States

Source: www.usda.gov
US / Mexico Border Counties Coalition
"At the Cross Roads: US / Mexico Border Counties in Transition"

Largest Aqueducts Diverting from the Lower Colorado River and from Rio Bravo Tributaries

FACILITY	SERVICE AREA	COMMENTS
Metropolitan Water District's (MWD's) Colorado River Aqueduct	Much of urbanized Southern California, including parts of Los Angeles, Orange, San Diego, Riverside, and San Bernardino Counties.	Historically, Colorado River water constituted more than half of MWD's imported supplies. About half of California's population lives within the MWD service area.
USBR's Central Arizona Project	Phoenix and Tucson metropolitan areas and neighboring agricultural regions	The Colorado River and its tributaries are the largest surface water source in the service area.
USBR's All American Canal	Imperial Valley agriculture and, via the Coachella Canal, agriculture in the lower Coachella Valley	The imported Colorado River water is the service area's only significant surface water supply.
Comisión de Servicios de Agua del Estado de Baja California Tijuana Aqueduct	Tijuana metropolitan area and Tecate	The imported Colorado River water is the service area's main surface water supply.
Servicios de Agua y Drenaje de Monterrey Linares-Monterrey Aqueduct	Monterrey metropolitan area	Rio Conchos, a Rio Bravo tributary, is the water source
Servicios de Agua y Drenaje de Monterrey El Cuchillo Aqueduct	Monterrey metropolitan area	Rio San Juan, a Rio Bravo tributary, is the water source

TABLE 4

climate change

in the Border Region

CHAPTER 3

CHAPTER 3

Impact Summary

In an emerging area of research, some climate scientists believe the jet stream is shifting poleward in both the northern and southern hemispheres, a shift that may be intensified by human-induced climate change. The jet stream affects the position of the winter storm track, determining which areas receive precipitation and which do not. The Hadley cell, an atmospheric circulation pattern that strongly influences tropical/subtropical climate, may be expanding as a result of climate change, in turn expanding the world's subtropical deserts adjacent to the moist tropical regions ***(Figure 13).*** The U.S. Southwest and Northwest Mexico lie within this area of expanding desertification. ***Figure 14*** shows the relationship between the position of the westerly winds (jet stream) and observed early spring precipitation.

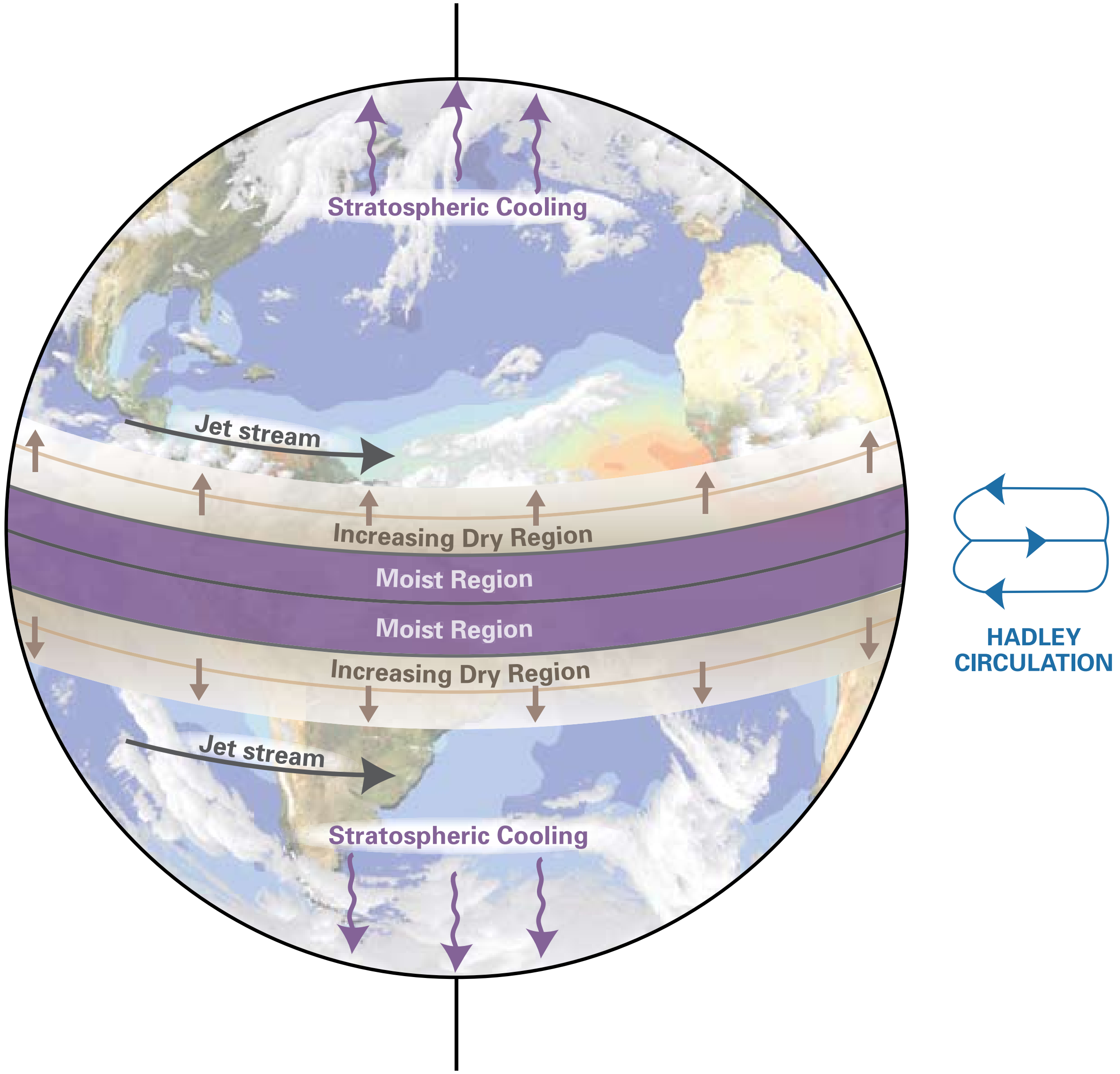


FIGURE 13

Global Position of Tropics/Sub-Tropics and Adjacent Desert Regions

Enhanced stratospheric cooling at very high altitudes above the polar regions also contributes to expansion of subtropical deserts, by pulling the jet stream northward.

Source: Southwest Climate Outlook, March 2008

The jet stream affects the position of the winter storm track, determining which areas receive precipitation and which do not. The Hadley cell, an atmospheric circulation pattern that strongly influences tropical/subtropical climate, may be expanding as a result of climate change…

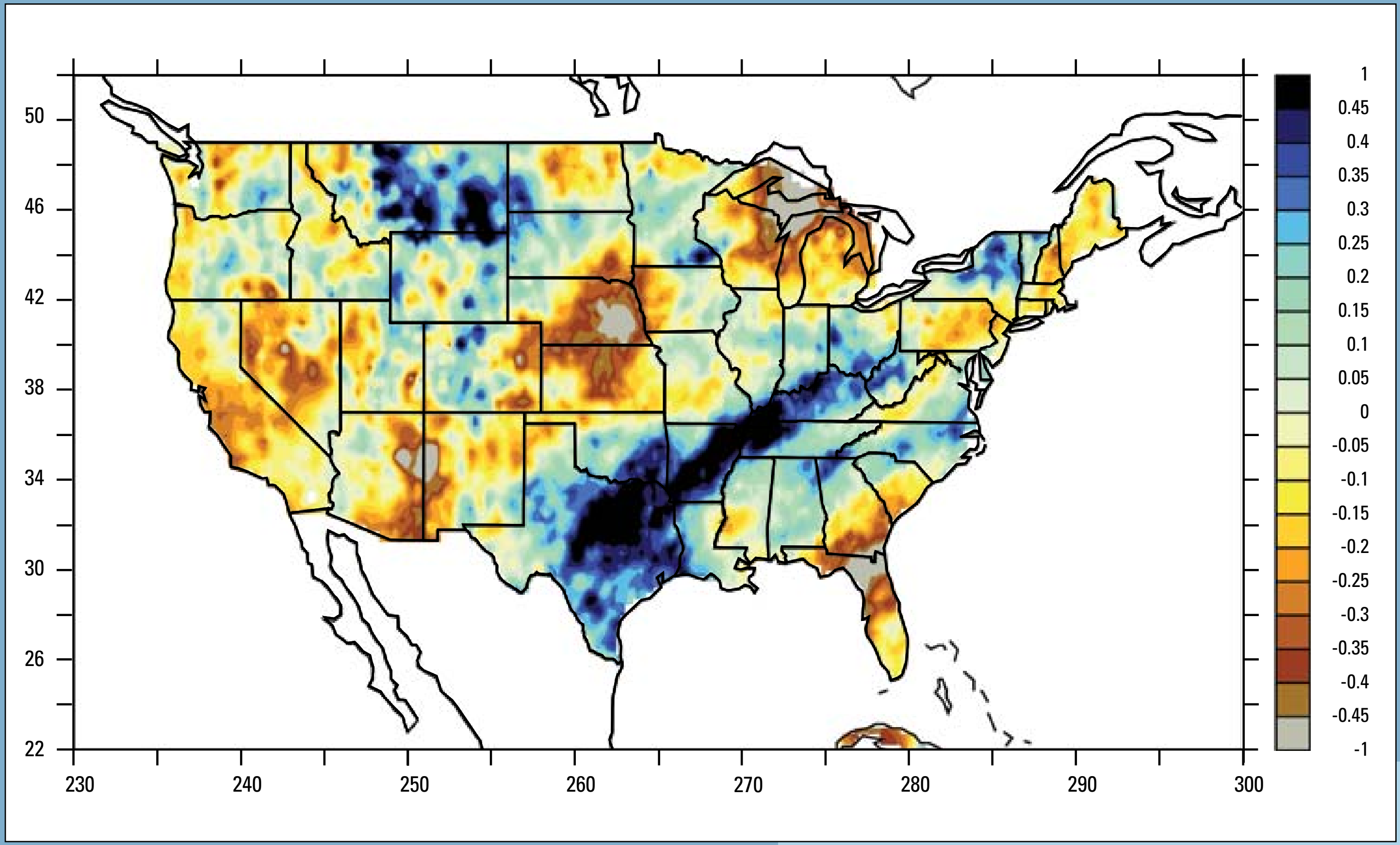
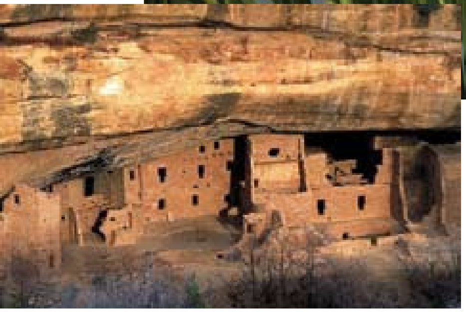


FIGURE 14

Correlation Between Winter Position of Westerly Storm Track (Jet Stream) and Precipitation Anomaly in Early Spring

Blue colors indicate increased precipitation and brown colors indicate decreased precipitation when the storm track is shifted north.

Courtesy of Stephanie McAfee, Joellen Russell, University of Arizona



Global climate modeling predicts that the already warm and arid U.S. Southwest and Mexican Northwest will become warmer and drier in the future. ***Figures 15*** and ***16*** present two views of this concept (based on use of two different global climate models) by comparing historical global precipitation with estimated future precipitation change, in which the locations of the existing desert belts north and south of the Tropics map well with regions of expected precipitation decreases. Another view of this concept is presented in ***Figure 17***, which shows the change in available water (characterized as precipitation less evaporation) estimated from multi-model projections.

In the immediate border area warmer temperatures would tend to increase evapotranspiration of agricultural crops and urban landscaping, leading to increases in the associated water needs. In the urban sector, increasing temperatures in the region's desert cities could affect patterns of future population growth. It is expected that not only will mean temperatures in the border area increase, but that the extremes (maximum temperatures) will as well, and that heat waves will likewise increase in frequency and severity. ***Figure 18*** presents a long-term record of days with high temperatures in excess of 100° F for selected large cities within the U.S. Colorado River/Rio Grande water use area. The data presented are influenced by multiple factors — including natural climate variability, urban heat island effect, and climate change — but illustrate the already hot conditions in the arid low-elevation interior West, as well as an apparent warming trend in the latter part of the record. Similar warming trends are also seen in regional gridded data sets of observed temperatures assembled by scientists from discrete measurements. ***Figures 19*** and ***20*** show such data for the Upper and Lower Colorado River Basin, at ground level and in the atmosphere. The spring atmospheric warming trend is significant in terms of implications for accelerated snowmelt runoff.

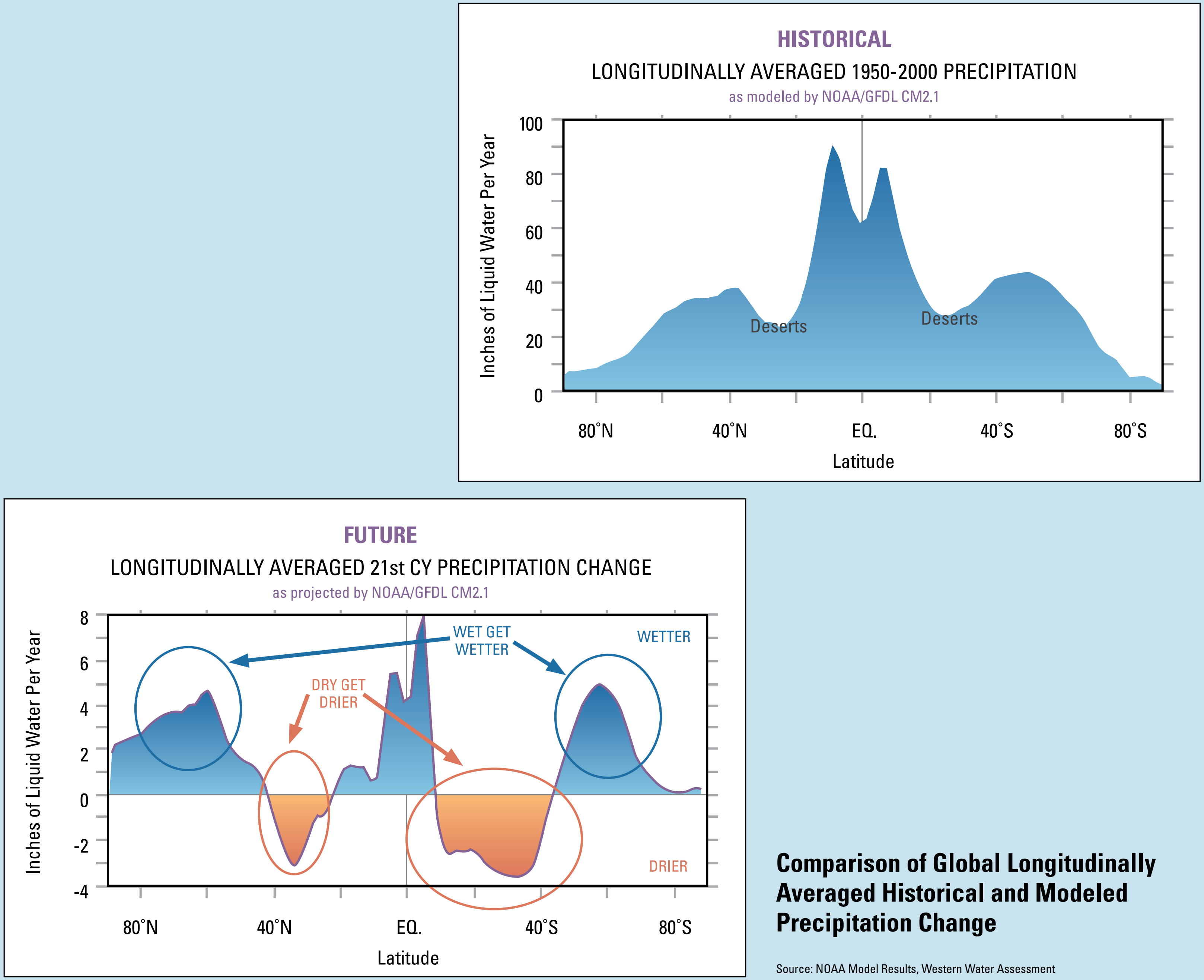


FIGURE 15

Comparison of Global Longitudinally Averaged Historical and Modeled Precipitation Change

Source: NOAA Model Results, Western Water Assessment

Annual Mean Precipitation Change: 2071 to 2100 Relative to 1990

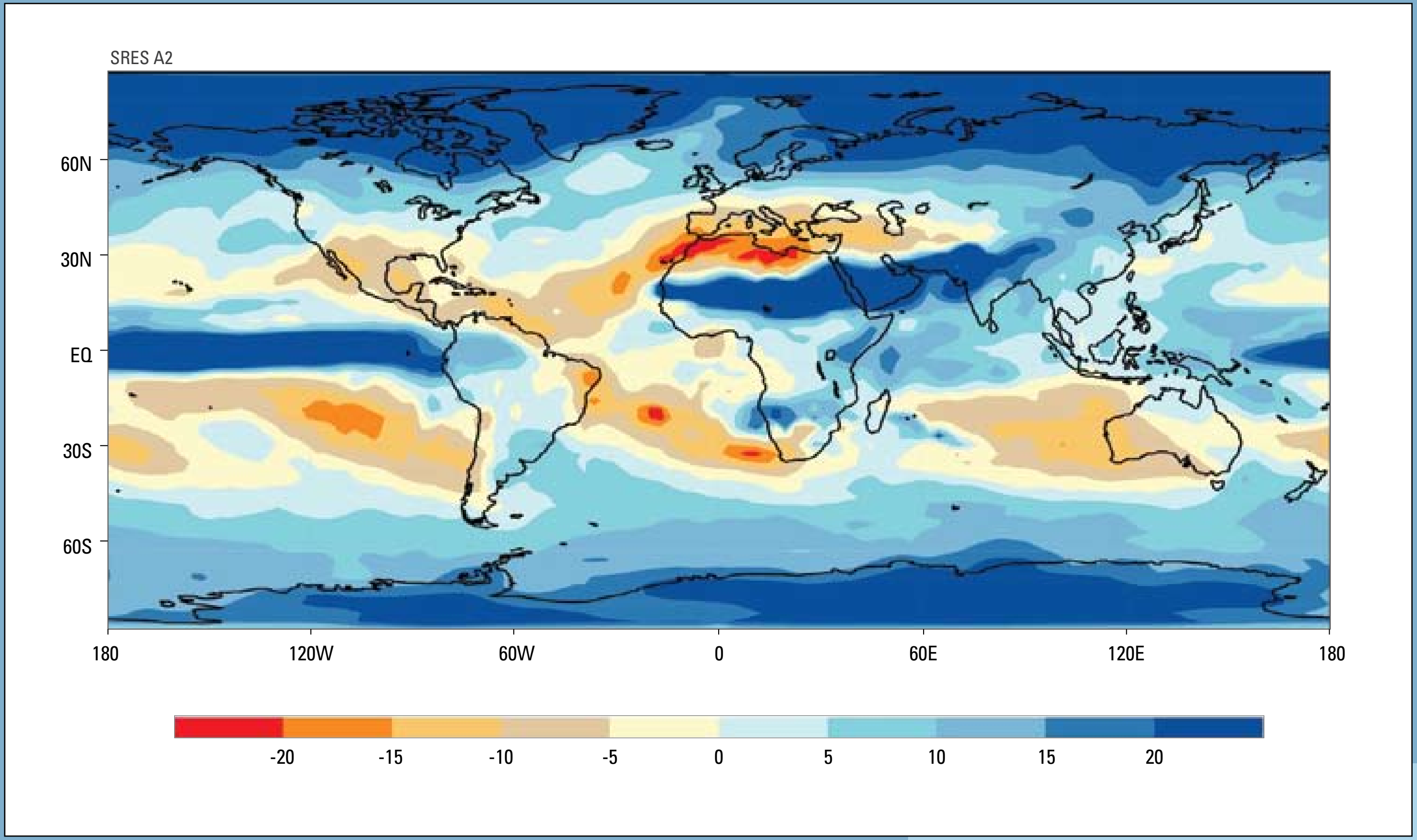


FIGURE 16

Global View of Annual Mean Precipitation Change, 2071 to 2100, Relative to 1990

Some areas are projected to become wetter, others drier.

Source: Joellen Russell, University of Arizona

Change in P-E (2021-2040 minus 1950-2000)

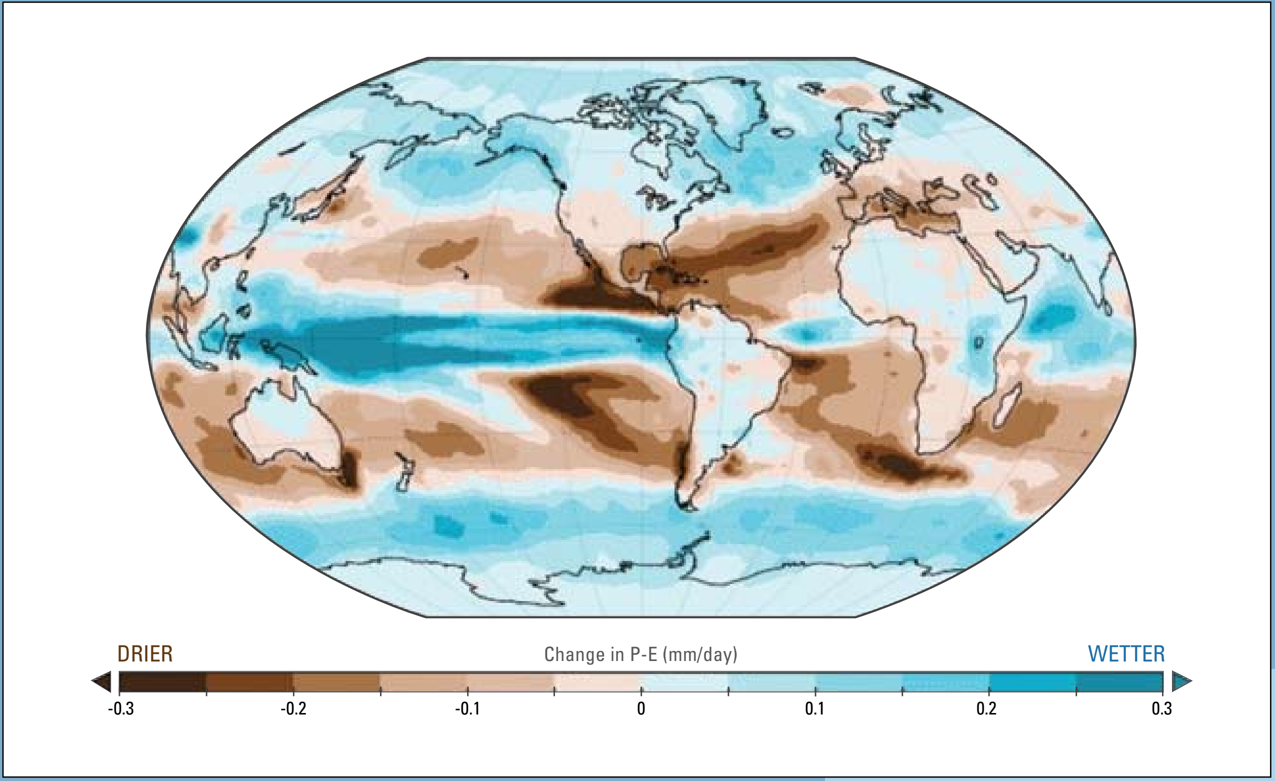


FIGURE 17

Multi-Model Simulation of Future Change in Precipitation Minus Evaporation

Change in P-E for the 2021-2040 period minus the average over 1950-2000. Results are averaged over simulations of the historical period and projections of the future with 19 different climate models. The future projections follow the middle-of-the-road SResA1B emissions scenario.

Source: CDWR, 2008, contributed by Richard Seager, Columbia University

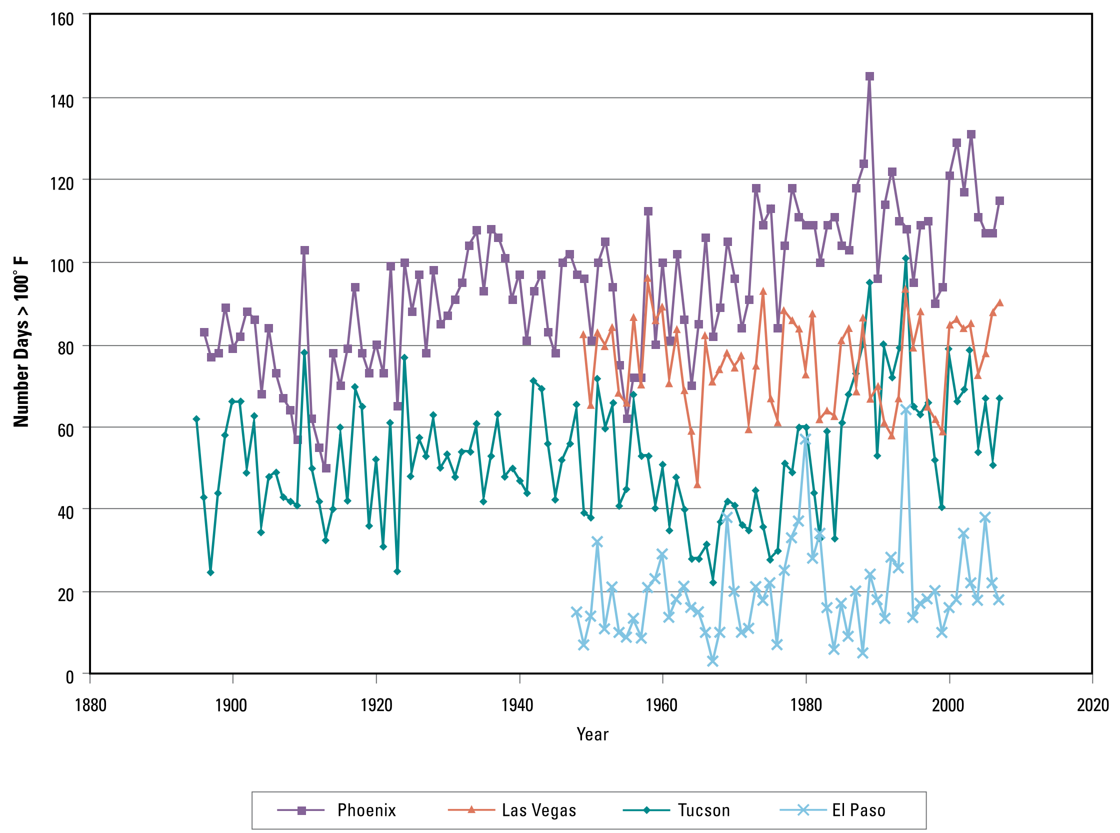
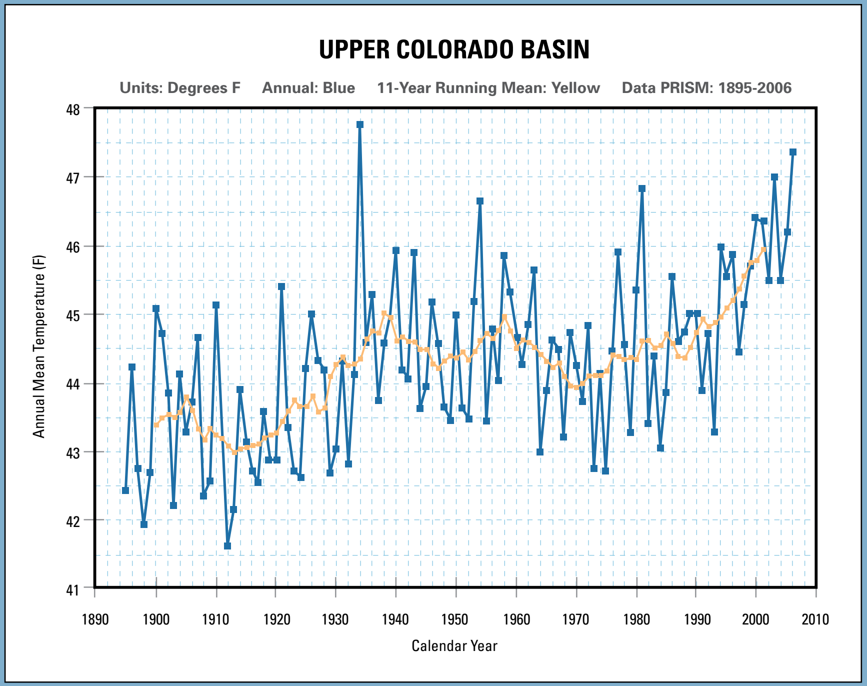


FIGURE 18

Number of Days with Temperatures in Excess of 100° F for Selected Cities

Source: Zack Guido, University of Arizona, and National Weather Service



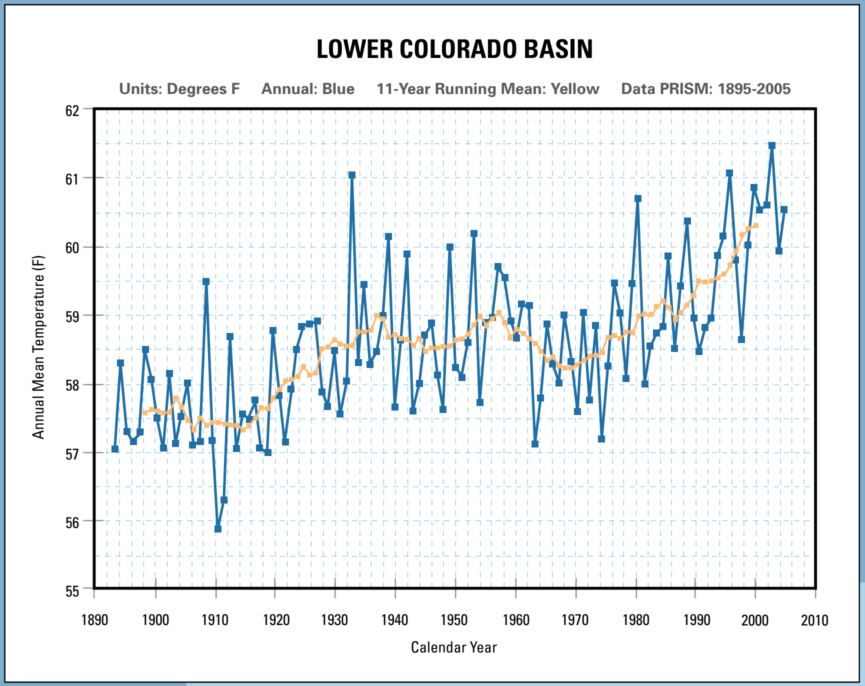


FIGURE 19

Observed Mean Annual Ground-Level Temperatures in the Upper and Lower Colorado River Basin

Source: Andrea Ray, NOAA; Brad Udall, University of Colorado; Kelly Redmond, Western Regional Climate Center

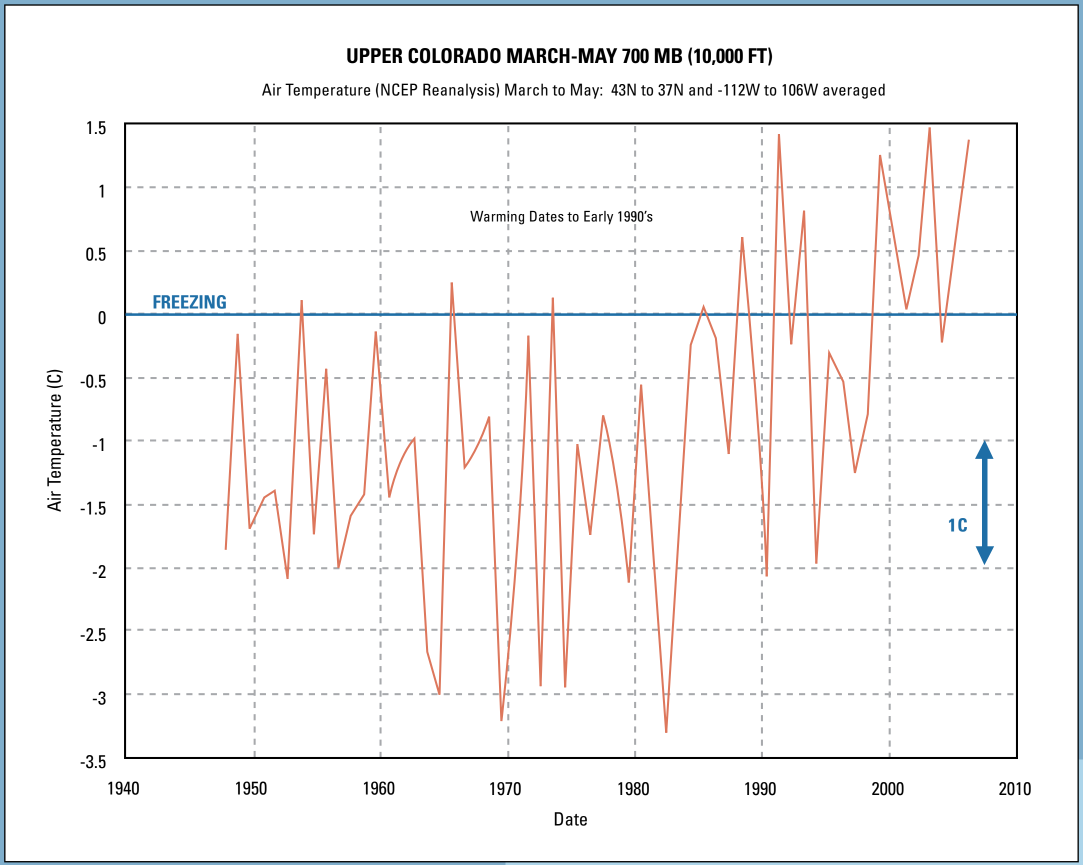


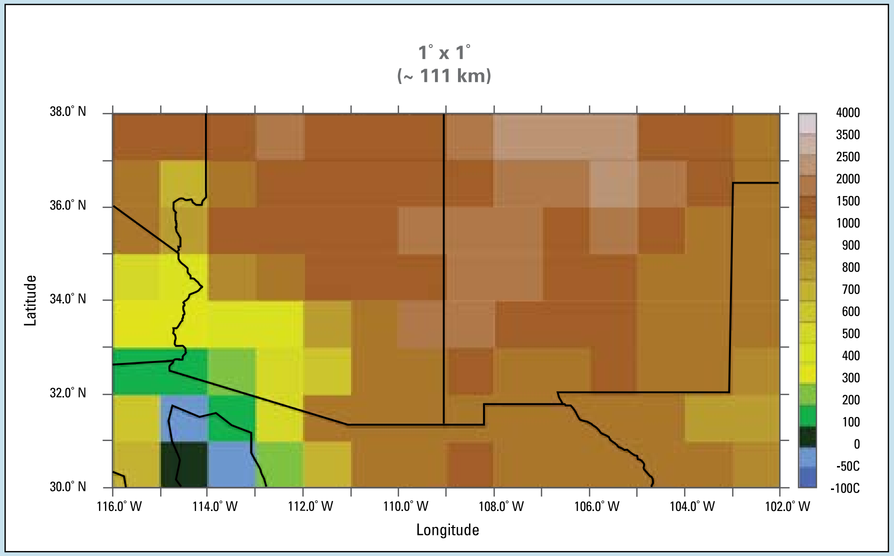
FIGURE 20

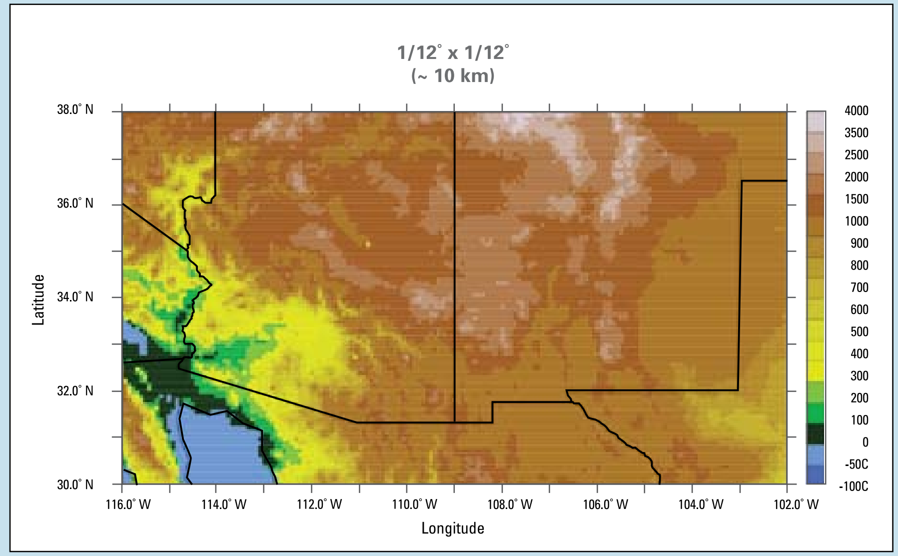
Observed Annual Atmospheric Spring Temperatures in the Upper Colorado River Basin

Source: Andrea Ray, NOAA; Brad Udall, University of Colorado; Kelly Redmond, Western Regional Climate Center

Climate Models

Over time, scientific understanding of climate processes and the ability to model climate at a global scale have been improving, allowing for better estimation of climate change impacts. Generally, there is greater confidence in the ability of the existing generation of models to predict increases in temperature than in precipitation. The necessarily large grid scales used in global models mask the effect of local topography, which plays an important role in observed climate patterns (as in the case of orographic precipitation). **Figure 21** illustrates how improving model resolution improves the representation of topographic features. Developing nested regional climate models (models that take the results of global-scale models and then simulate conditions at a much smaller scale) and obtaining the computing resources to run them at the desired resolution are a high priority for climate change science research.





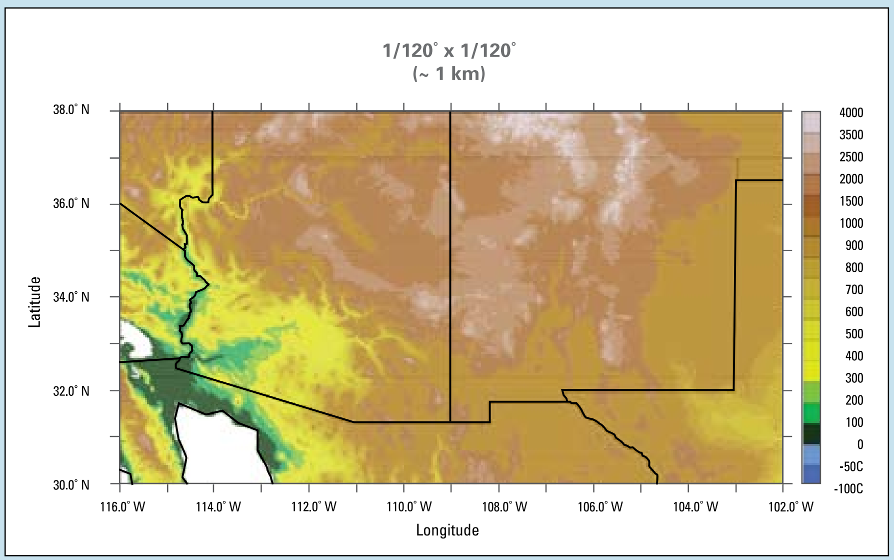


FIGURE 21

Effects of Climate Model Resolution on Representation of Topography

Source: Joellen Russell, University of Arizona

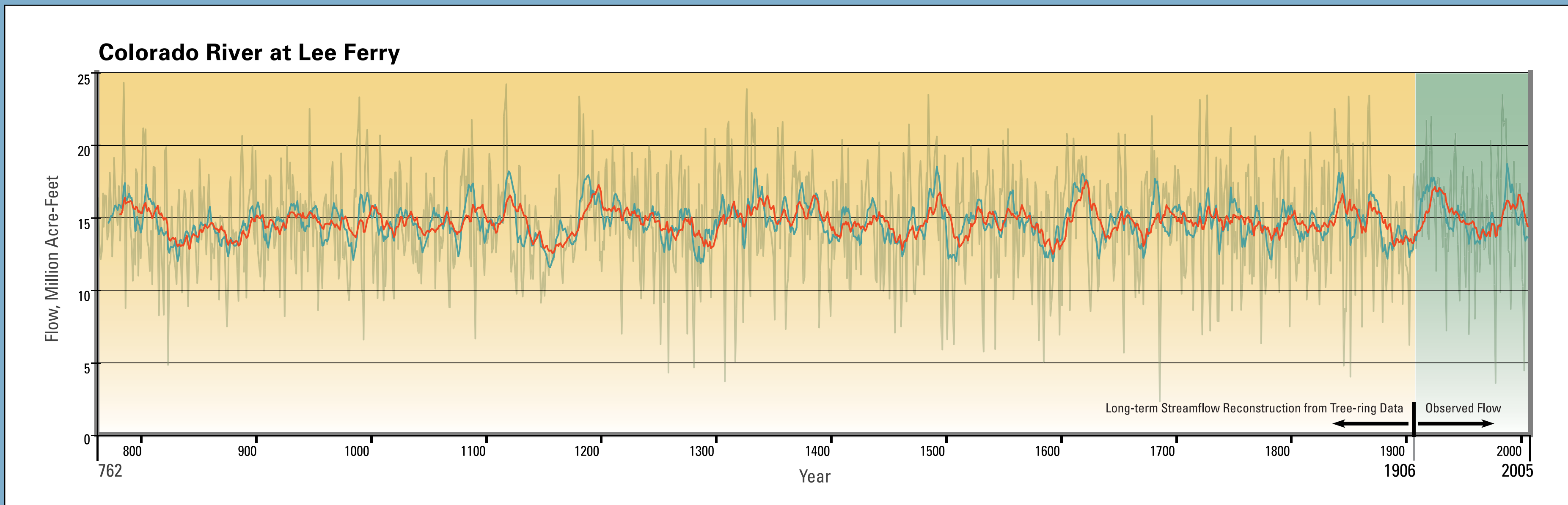
Impacts of climate change are important not only in the immediate vicinity of the border region, but also in the upper watersheds of the Colorado River and Rio Grande, where much of the region's surface water supplies are produced from snowmelt runoff.

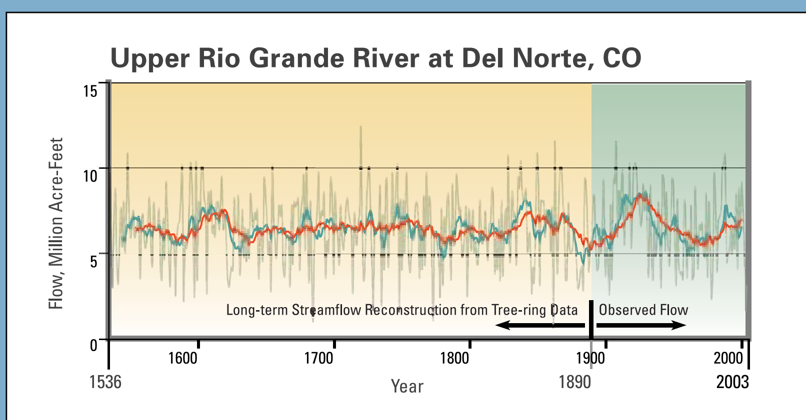
The present level of development in both river basins has occurred during a period of wetter than average conditions, in comparison to long-term paleoclimate records. The 1922 Colorado River Compact, for example, was negotiated based on the wettest period of the then-available historical record of observed streamflow; the longer historical record now available suggests that the river is over-allocated with respect to Compact apportionments. Even longer-term reconstructions of the river's flow based on tree ring data show that the basin has experienced decades-long periods of drought, periods much longer than those experienced in the short period of the historical gaged record, a circumstance that also holds true for the headwaters area of the Upper Rio Grande. ***(Figure 22).*** A 2007 National Research Council study on hydroclimate variability in the Colorado River Basin noted that:

Multicentury, tree-ring based reconstructions of Colorado River flow indicate that extended drought episodes are a recurrent and integral feature of the basin's climate. Moreover, the range of natural variability present in the streamflow reconstructions reveals greater hydrologic variability than that reflected in the gaged record, particularly with regard to drought.

Figure 23 shows one analysis of projected changes in annual runoff for the U.S. from 2041-2060, based on multi-model results. Impacts of climate change in the Colorado River Basin have been the focus of multiple recent studies, reflecting the importance of this water supply in the arid West. ***Table 5*** summarizes results of some recent studies. Although different studies using different models or analytical techniques yielded a range of results, all were in agreement that the outcome would be a decrease in precipitation or runoff.

Colorado River and Upper Rio Grande River





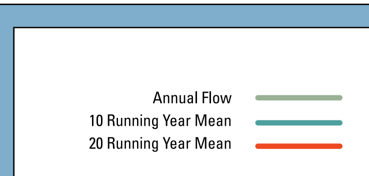


FIGURE 22

Long-Term Colorado River and Upper Rio Grande Streamflow Reconstructions

1. Colorado River reconstruction is for flow at Lee Ferry, the dividing point between the Upper and Lower Colorado River Basin.
2. Rio Grande reconstruction is for the headwaters area at Del Norte, Colorado.

Data courtesy of Dave Meko and Connie Woodhouse, Laboratory of Tree-Ring Research, University of Arizona

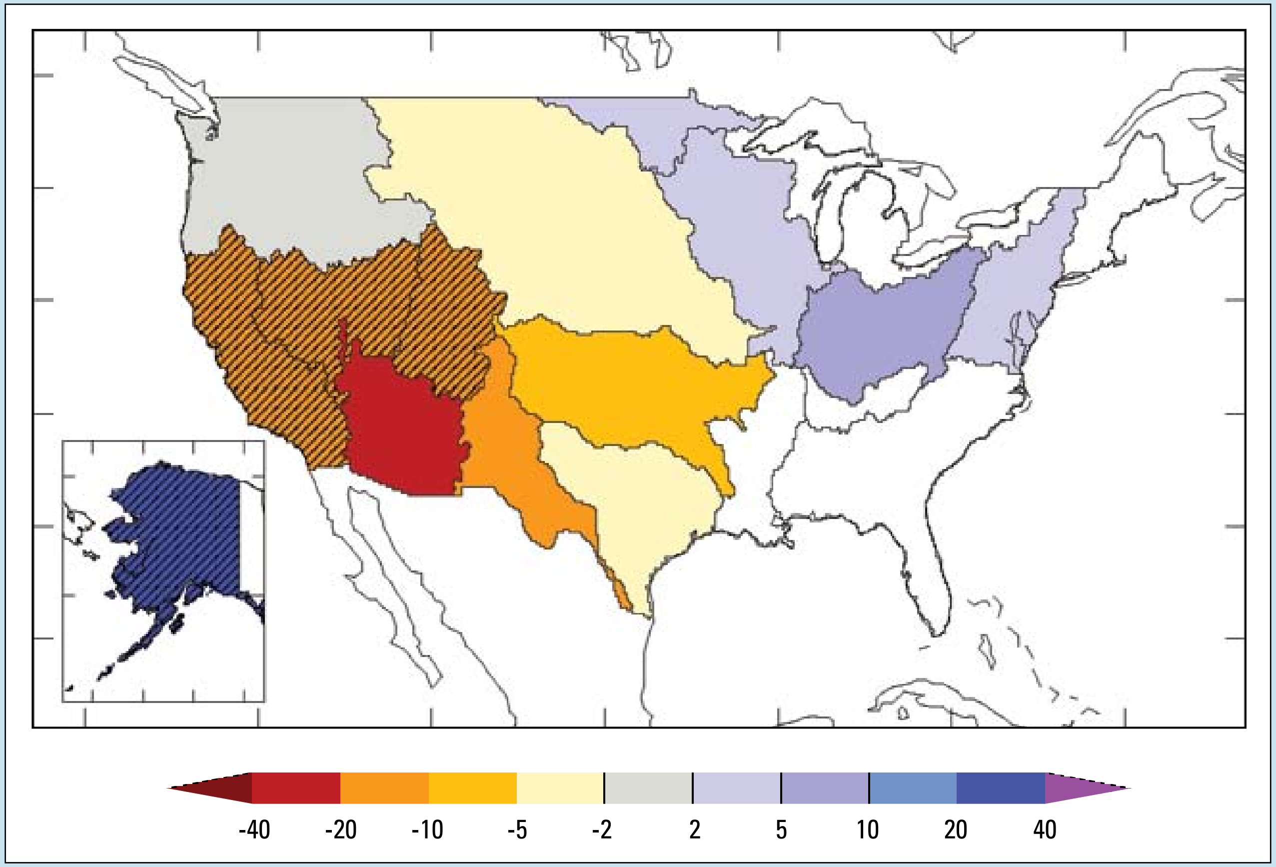


FIGURE 23

Model-Projected Changes in U.S. Annual Runoff, 2041-2060

Percentage change relative to 1900-1970 baseline. Any color indicates that >66% of models agree on sign of change; diagonal hatching indicates >90% agreement. After Milly, P.C.D., K.A. Dunne, A.V. Vecchia, Global pattern of trends in streamflow and water availability in a changing climate, Nature, 438, 347-350, 2005.)

Source: CDWR, 2008, contributed by Brad Udall, University of Colorado

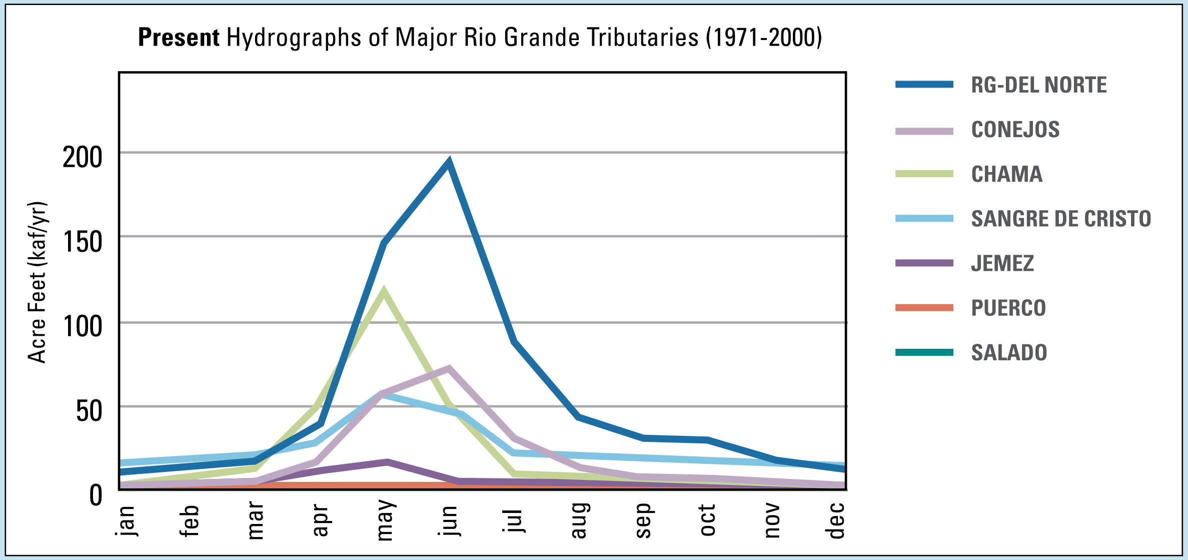
Generally, expected increases in temperature in the mountain rain-to-snow transition elevation range would result in reduced snowpack area, a shift in the timing of snowpack runoff to earlier in the spring, and increased evaporation or sublimation losses. Although climate change impacts have not been studied as intensively in the Rio Grande Basin as they have in the Colorado, these temperature effects are apparent in work that has been done, as illustrated in ***Figure 24***.

Also important in the lower Colorado River Basin and Rio Grande Basin are potential changes in summer rainfall — namely the monsoon season. The Rio Grande Basin in northwestern Mexico receives much of its precipitation as summer rainfall, as illustrated in ***Figure 25***. Moisture from the Gulf of California and Gulf of Mexico is carried over the continental landmass, where it is heated as it rises over mountain ranges, typically yielding afternoon thunderstorms and sometimes accompanying flash flooding ***(Figure 26)***. Observed climate data suggest that the intensity of rainfall during

Summary of Studies since 2004 on the Colorado River

STUDY NAME	TYPE OF STUDY	RESULTS	COMMENTS
Christensen et al., 2004	Colorado River Specific GCM + Hydrology	-18% runoff by 2040-2069	Only 1 climate model, 1 hydrology model. Superseded by 2006 study.
Christensen and Lettenmaier, 2006	Colorado River Specific GCM + Hydrology	-6% runoff by 2040-2069	11 climate models, 1 hydrology model.
Hoerling and Eischeid, 2006	Colorado River Specific GCM + Hydrology	-50% by 2035-2060	18 Climate Models, very simple hydrology model.
Milly et al, 2005	Global Climate Model Runoff	Approximately -20% runoff by 2041-60	Study showed 12 GCMs can reproduce historical runoff around globe and by implication project future runoff.
Seager et al, 2006	Global Climate Model Runoff Proxy	Approximately -10% runoff by 2041 to 2060	19 climate models. Modeled are doesn't include entire Green River Basin, also includes large parts of the Southwest not part of Colorado River Basin.
IPCC, 2007	Global Climate Model Precipitation	No number, but precipitation decrease 'likely'	Approximately 20 climate models. Determination is for annual mean precipitation, not runoff. Finding is based on "near unanimity among models with good supporting physical insights."

TABLE 5



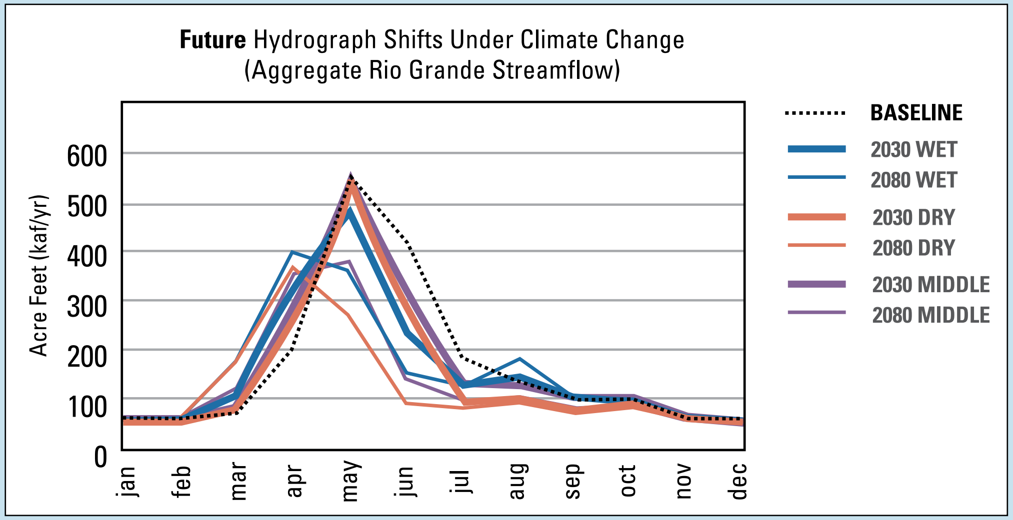


FIGURE 24

Comparison of Present and Predicted Rio Grande Streamflow Hydrographs

Source: Brian Hurd, New Mexico State University
and Albert Rango, USDA

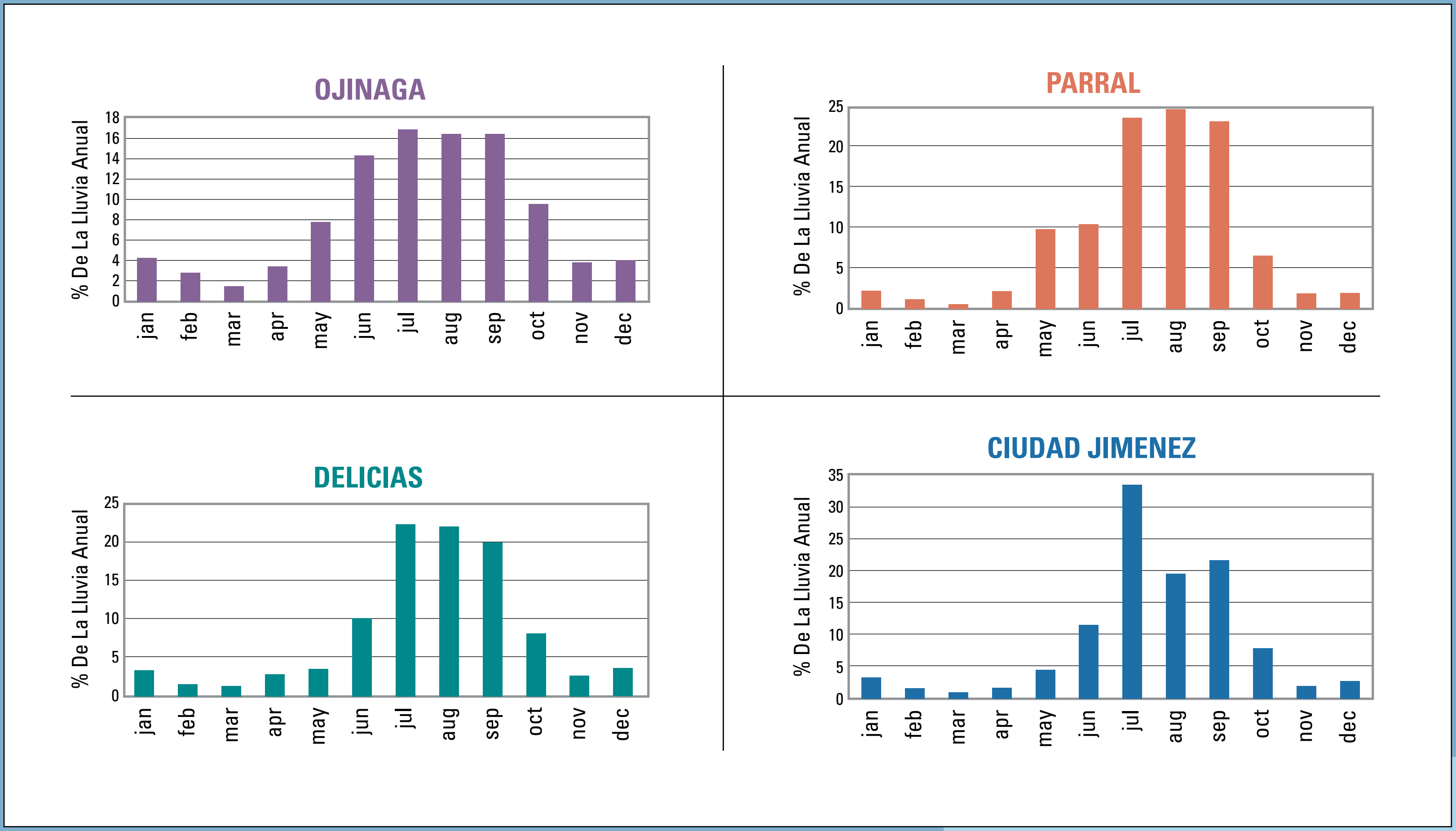


FIGURE 25

Importance of Summer Precipitation at Selected Sites in Rio Conchos Basin

Source: Tereza Cavazos, CICESE

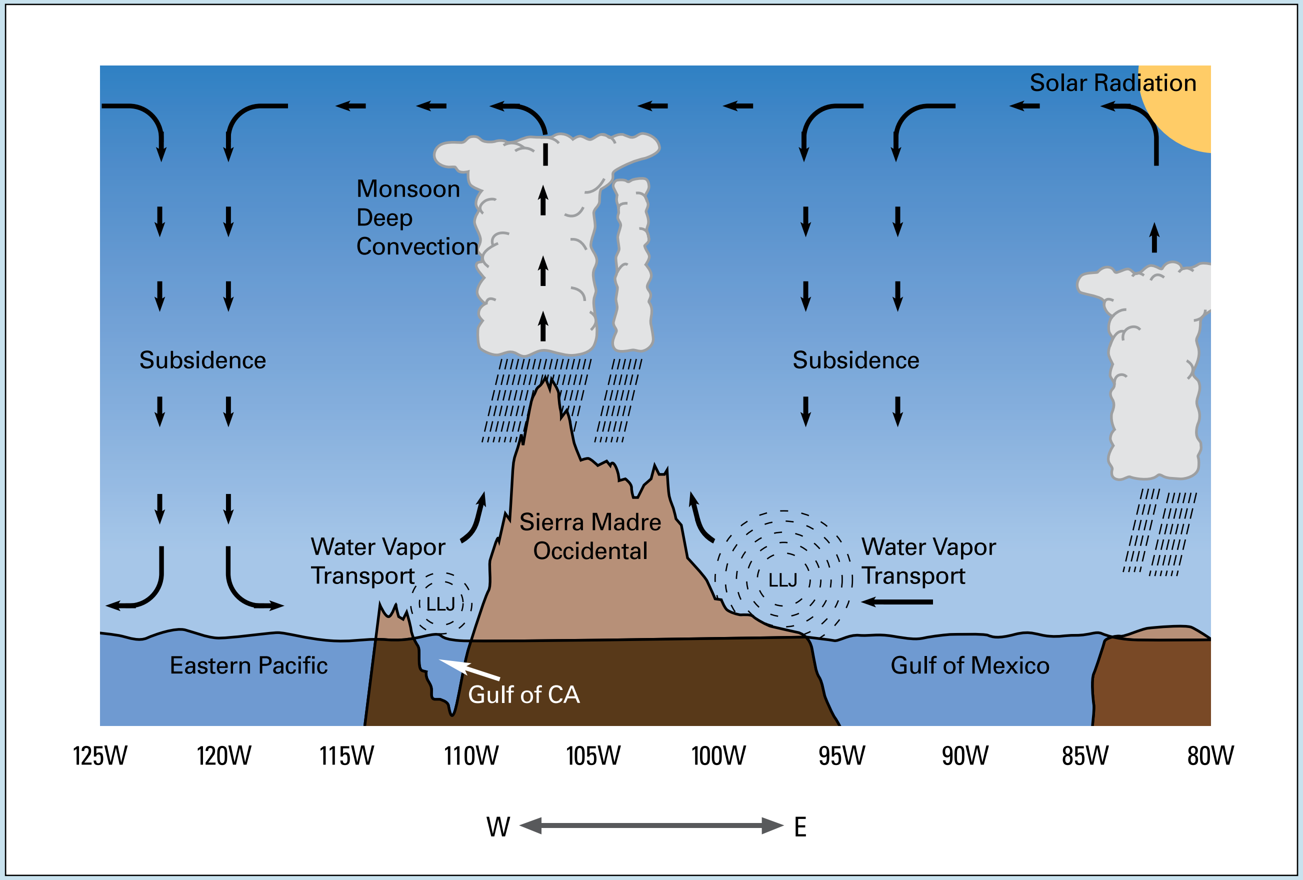


FIGURE 26

Elements of the North American Monsoon Over Northern Mexico

Source: NOAA, W. Higgins

monsoon events may be increasing (increasing the potential for flash flooding), but simulating the monsoon season is not a strong point of the current generation of global climate models, limiting predictive capability.

Quantification of sea level rise is another aspect of climate change where uncertainty remains. Sea level rise is a gradual phenomenon, but an important one for low-lying coastal areas — especially those bordering the Gulf of Mexico where the potential for tropical storms/hurricanes exists. In addition to increased storm surge flood risks for coastal infrastructure, sea level rise could also contribute to increased seawater intrusion in coastal aquifers. ***Figure 27*** compares estimated or measured historical global mean sea level data with projections of future change for one greenhouse gas emissions scenario. (For a variety of reasons, including tectonics, sea level rise is not globally uniform). Recent observations of Arctic ice sheet melting have pointed out that some aspects of ice sheet dynamics are not well understood; that lack of understanding precluded their being factored into the IPCC Fourth Assessment projections of sea level rise.

Water quality impacts due to climate change will depend on site-specific circumstances. Warmer water temperatures, increased incidences of flash flooding, and more frequent and severe droughts could all have negative impacts on water quality. Increased transport of, or exposure to, pollutants such as sediment, salts, nutrients, and pathogens are possible outcomes of expected hydroclimate changes. Sensitive aquatic species would be likely to be first affected; although water temperature impacts could be positive for some fish species, such as native fish species in the lower Colorado River that currently face competition from coldwater non-native sport fish. Presently, there is a dearth of site-specific information on border-area water quality impacts due to climate change.

In summary, presently available climate change research for the border area predicts the following outcomes relevant to water resources management:

- Increased water demands due to warmer temperatures.
- Reduction of snowpack and a shift in timing of snowmelt runoff to earlier in the spring (more rain, less snow).
- Reduced runoff.
- Increased likelihood of extreme events (droughts and floods).
- Gradual rise in sea levels

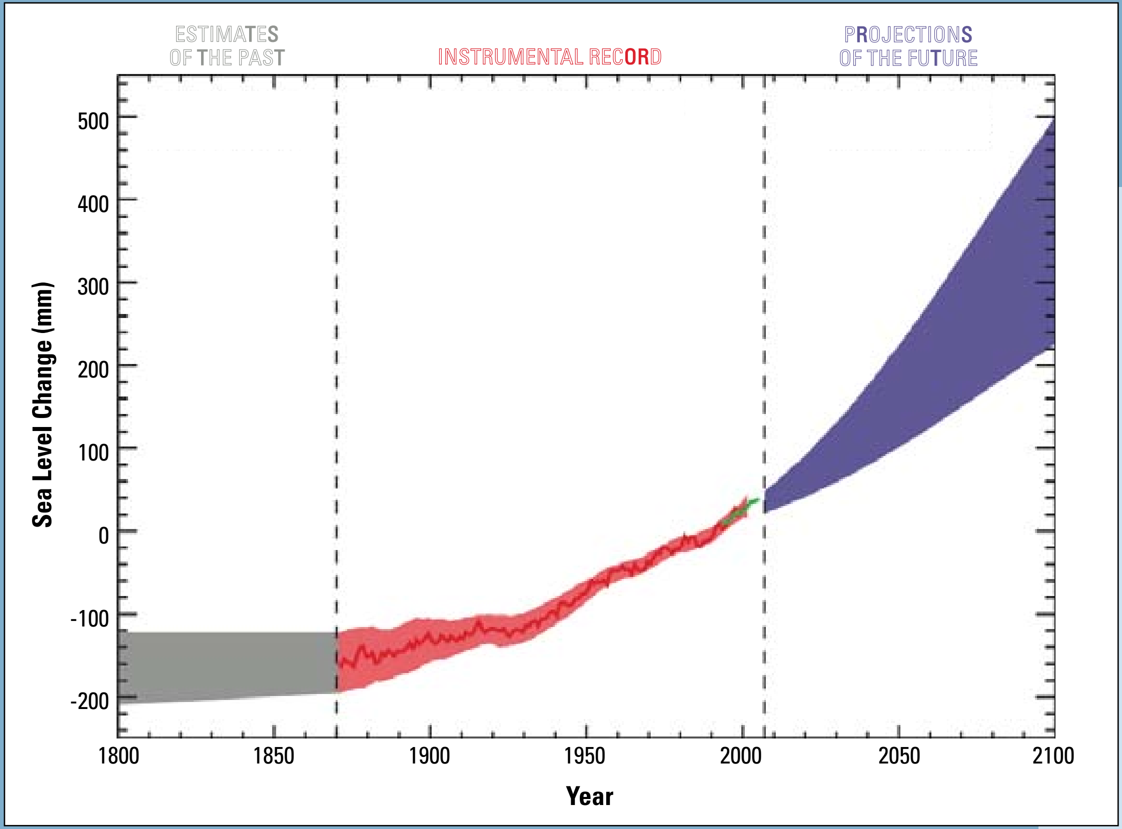


FIGURE 27

Comparison of Historical and Predicted Sea Level Rise

Time series of global mean sea level (deviation from the 1980-1999 mean) in the past and as projected for the future. For the period before 1870, global measurements of sea level are not available. The grey shading shows the uncertainty in the estimated long-term rate of sea level change. The red line is a reconstruction of global mean sea level from tide gaug\es and the red shading denotes the range of variations from a smooth curve. The green line shows global mean sea level observed from satellite altimetry. The blue shading represents the range of model projections for the SRES A1B scenario for the 21st century, relative to the 1980 to 1999 mean, and has been calculated independently from the observations. Beyond 2100, the projections are increasingly dependent on the emissions scenario. Over many centuries or millennia, sea level could rise by several metres.

Source: IPCC Fourth Assessment, Working Group 1 Report, FAQ 5.1, Figure 1

Research and Data Needs

There are areas where focused research or information development are needed to allow water managers to better adapt to and manage the expected impacts of climate change. Analytical uncertainties associated with addressing climate change impacts should be addressed sooner rather than later, as results of such analyses are necessary early in the process of developing adaptation strategies. Importantly, establishment and maintenance of adequate hydroclimate monitoring networks is an essential component of adapting to climate change. Examples of research and data needs include:

Estimates of snow water content obtained from telemetered snow sensors (snow pillows) and from manual measurements of snow courses provide the foundation for forecasting snowmelt runoff.

- Preserving existing observational networks (e.g., streamgages) and preventing further network deterioration and loss of stations.
- Expanding monitoring networks to encompass high elevation mountain areas at the critical rainfall-snow interface.
- Filling in other gaps in hydroclimate monitoring, including gaps associated with detection and attribution.
- Designing remote sensing technologies for climate monitoring and transitioning them to operational applications (e.g. use of the MODIS sensor installed on the National Aeronautics and Space Administration's (NASA's) Aqua and Terra satellites).
- Developing regional climate models capable of producing high-resolution outputs at a river basin scale.
- Improving understanding of the interaction of seasonal to inter-annual cycles such as the El Niño – Southern Oscillation with climate change effects.
- Developing paleoclimate data sets (streamflow and precipitation reconstructions) that quantify past natural climate variability.
- Improving long-range weather forecasting and climate prediction capabilities.

CHAPTER 4

Changes in the range and abundance of temperature-sensitive species will be one ecosystem impact of a changing climate. In the Lower Rio Grande, warming temperatures may allow expansion of the range of the nine-banded armadillo, the only armadillo species found in the U.S. On the other hand, warming temperatures are a threat to the American pika, which is found in high elevation mountain settings in locations such as the Rocky Mountains of Colorado or California's Sierra Nevada.

Adaptation in Perspective

Climate change impacts are one of multiple factors that need to be considered in water management planning in the border region. Within the planning horizon typically used for water management — to at most 2050 — it is expected that demographic changes will remain the major driver for border water needs and water infrastructure. Although global climate model results are available for 2100 and beyond, it is not realistically possible to forecast demographic variables (population projections and distribution), land use, and water use with the accuracy or level of detail needed for water management planning beyond 2050. Many circumstances may affect key demographic variables in the latter part of this century, including the impacts of climate change. It is also important to recognize that uncertainties associated with the mechanics of global climate models dominate the near-term modeling results; beyond that time the choice of greenhouse gas emissions scenarios assumed for the modeling strongly influences model outcomes.

Conflicting science predictions associated with climate change impacts, and the predictions' lack of detail, complicate translation of potential impacts into specific criteria that could be used for design and operation of water infrastructure. Some impacts, such as the likelihood of increased, possibly more intense, floods and droughts, are not presently quantifiable. Uncertainties associated with precise quantification of climate change impacts suggest the desirability of employing multiple adaptation strategies, sometimes referred to as a portfolio approach. The normal tools that water agencies use to design for and manage extreme events — droughts and floods — are suitable for climate change adaptation; the difference lies in the need to broaden the criteria used for their application. Adaptive management — monitoring conditions actually being experienced and adjusting responses to respond to observed conditions — will be a key element of the process.

The development of adaptation strategies in the border region can be enhanced through a binational approach to adaptation. Emerging transboundary collaboration on the Colorado River, for example, would lay a good foundation for working on strategies in the future. There, the U.S. and Mexican Sections of IBWC are beginning a joint cooperative process to identify, explore, and ultimately implement selected water conservation, shortage management, augmentation, and environmental initiatives with binational benefits. IBWC established a binational core group to address joint cooperative actions in early 2008, and the group has begun meeting to scope activities to pursue.

The Commissioners of the U.S. and Mexican Sections of IBWC have been working closely on the new collaborative process for the Colorado River.

Key Climate Change Definitions

The terms mitigation and adaptation are widely used in the climate change community, where they have specific meanings. The IPCC Third Assessment Report defined them as follows:

Mitigation – *An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.* (Examples of mitigation measures would include establishing new vehicle standards to reduce GHG emissions, or developing carbon sequestration programs.)

Adaptation – *Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.* (Examples of adaptation could include modifying reservoir flood control operations rule curves or constructing seawalls.)

Most water agency climate change activities fall into the category of adaptation, although activities that reduce energy use (through conservation) or result in a shift to energy sources with a lower carbon footprint could be classified as mitigation.

Adaptation Strategies

Streamflow reconstructions derived from tree-ring records are a useful tool for evaluating severity of droughts outside the period of measured historical records.

Planning for water management and flood control should take into account both expected consequences attributed to climate change and uncertainties that cannot be quantified or well quantified at this time.

Traditional hydrologic analysis and design have been based on the premise that the past is the key to the present (also known as climate stationarity), and on relatively short records of measured hydrology. There is as yet no broadly accepted analytical technique to replace the traditional approach, although use of long-term records reconstructed from paleoclimate information is a practical approach for analyzing climate variability within near- to mid-term planning timeframes for water supply and drought preparedness purposes.

Photo courtesy of Connie Woodhouse, University of Arizona

Institutional tools that facilitate adaptation include:

- Avoidance of impacts in new development through land use planning (e.g. appropriate floodplain management).
- Incorporation of risk management into the decision-making process (through insurance or through acceptance of varying levels of risk based on specified criteria).
- Use of appropriate safety factors to help mitigate uncertainties.
- Reoperation or repurposing of existing facilities to better respond to changing hydrologic conditions (e.g. changing reservoir flood control rule curves).
- Preparation of adaptive management plans that include action triggers and monitoring to determine when triggers are reached.

Water management planning should make explicit use of approaches that diversify water supply sources where possible, and take advantage of opportunities offered by integrated regional planning. Water use efficiency and conservation are an important component of this process. Access to regionally shared infrastructure — including storage (whether surface water reservoirs or groundwater basins) and conveyance facilities — is an essential tool to enable regional response actions such as voluntary water transfers and exchanges.

Integrated Regional Planning in California

The 2005 update of the California Water Plan recommended promoting integrated regional water management to "ensure sustainable water uses, reliable water supplies, better water quality, environmental stewardship, efficient urban development, protection of agriculture, and a strong economy". Proposed elements of that approach were defined as fostering regional partnerships, developing and implementing integrated regional water management plans, and diversifying regional water portfolios. A bond measure approved by the state's voters in 2006 authorized, among other things, the appropriation of one billion dollars to CDWR for fostering integrated regional water management. Grants to local agencies pursuant to this provision are conditioned on the agencies' implementation of integrated regional water plans or their functional equivalents, with the statute further establishing an allocation of funds by geographic area.

The substantial amount of storage on the Colorado River system serves as insurance against hydrologic variability, and allows lead time for putting adaptive management measures into play during droughts. Recent adoption of new interim guidelines for managing Lakes Mead and Powell under shortage conditions allow U.S. agencies using Colorado River water to store a portion of their conserved supplies in Lake Mead on a space-available basis; part of this dedicated storage has not yet been allocated and could be made available for water users in Mexico, subject to IBWC negotiations.

Subjects covered at CDWR's border water infrastructure conference included the need for funding to maintain IBWC's aging binational infrastructure and examples of conveyance and agricultural water use improvements.

Border Water Infrastructure

Evaluation of climate change adaptation strategies in the border region is not complete without considering the special circumstances associated with how border water infrastructure may be developed and financed. Briefly, a side agreement to the North American Free Trade Agreement of 1993 established, among other things, BECC and the North American Development Bank (NADBank). The role of BECC is to develop and certify environmental infrastructure projects (e.g. water and wastewater infrastructure projects) meeting specified criteria, which may then be financed through NADBank via a combination of loans and grants. BECC's area of coverage is within 62 miles (100 kilometers) of the border on the U.S. side and 186 miles (300 kilometers) on the Mexican side ***(Figure 28). Figure 29*** from BECC shows the history of U.S. funding for this infrastructure development program. Generally, much of the funding expended to date has been used for stand-alone municipal projects, such as wastewater treatment plant construction, in the border zone. BECC has documented nearly $1 billion of additional needs for border-area drinking water and wastewater infrastructure.

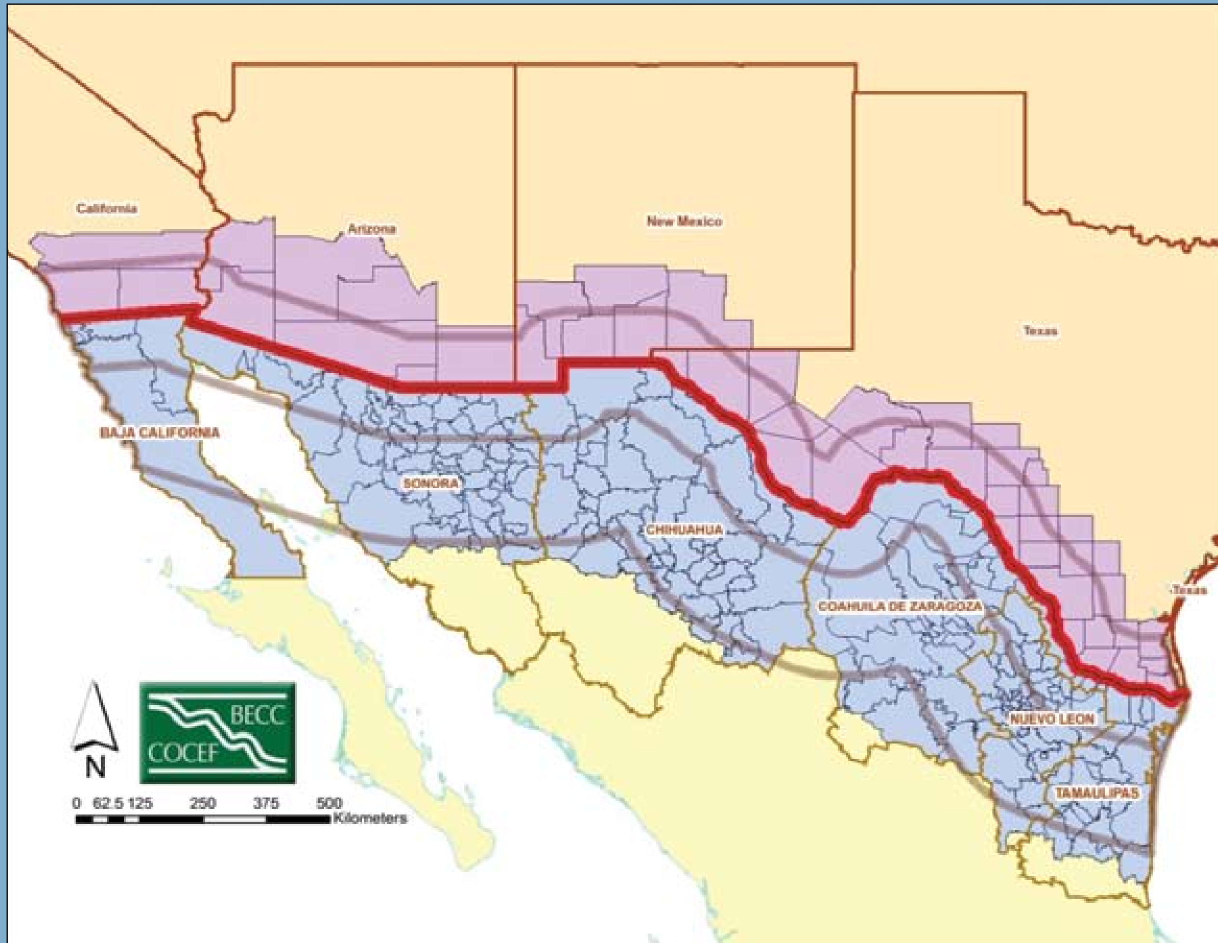


FIGURE 28

100 & 300 km BECC Border Zone

Mexican Municipalities within 300 km BECC border zone:

- 224 municipalities in 6 states
- Area 697,000 km^2
- Population 16.5 million inhabitants

Source: CONAPO 2007; SNIM version 7.0 and INEGI 2000

US Counties within 100 km BECC border zone:

- 47 counties in 4 states
- Area 375,000 km^2
- Population 13.2 million inhabitants

Source: US Census Bureau Office 2006

US Appropriations To US-Mexico Border Program (1994-2009)

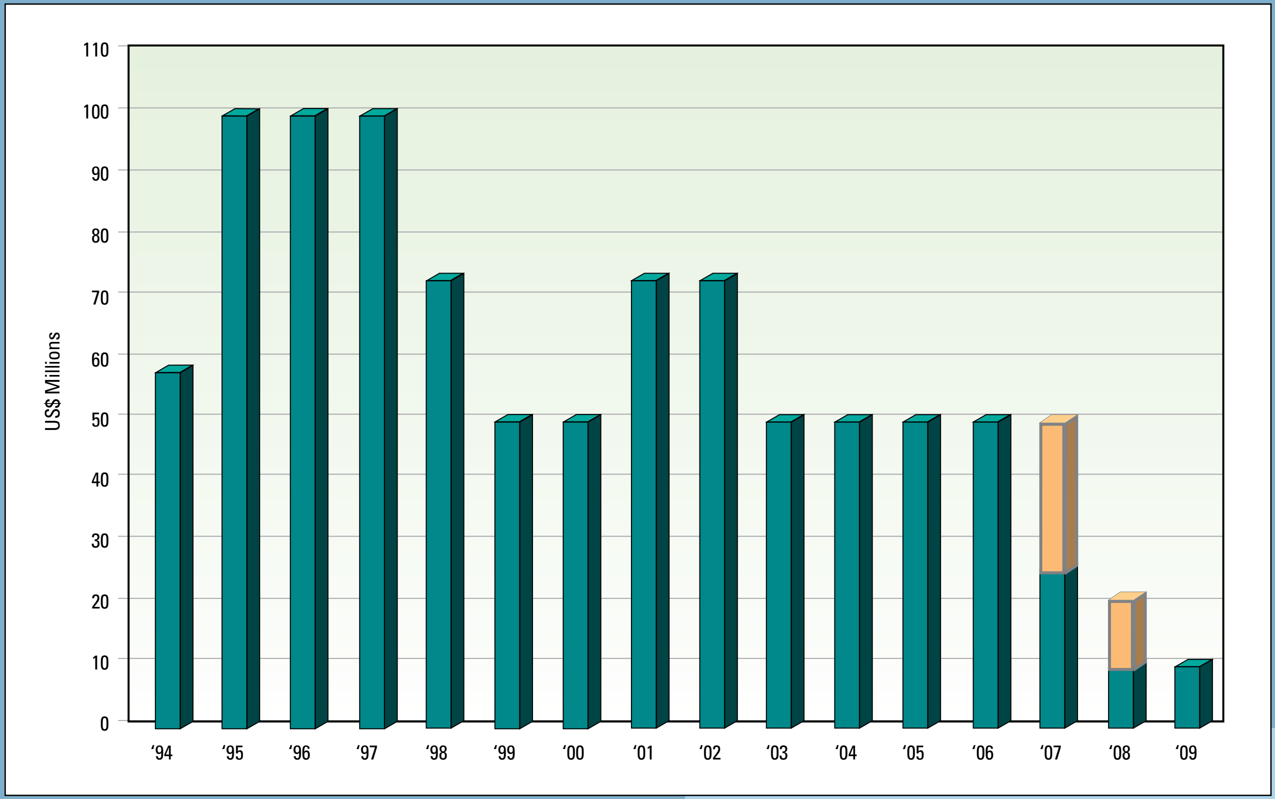


FIGURE 29

History of U.S. - Mexico Border Program Appropriations

FY2007, FY2008 and FY2009 reflect President's budget proposed amounts.FY2007 received US$50 Million by way of Continuing Resolution and FY2008 received US$20 Million through Congressional support.

Source: BECC

Satellite image courtesy of NASA

Irrigated farmland in the Imperial Valley in the U.S. and the Mexicali Valley in Mexico. The Gulf of California is at the lower right.

CDWR cosponsored a May 2008 conference on border water infrastructure and financing needs, at which presenters from the U.S. and Mexico discussed infrastructure development plans and expected future needs, and challenges in meeting those needs. It was pointed out at the conference that the current paradigm of project funding via BECC/NADBank, as well as historical infrastructure needs assessments for the border region, have generally not addressed regional water management tools such as water conveyance infrastructure, water storage/reservoir management, agricultural water use efficiency, groundwater recharge, or water recycling and desalination. Apart from a one-time NADBank water conservation investment fund grant program in 2002 intended to help respond to impacts of drought and Mexico's Rio Grande water debt, existing financial assistance programs have not employed a regional approach.

Expanding border infrastructure financial assistance programs to incorporate a regional perspective on infrastructure development would be a useful step to more efficient water management and would help build a framework for long-term adaptation to climate change. In particular, opportunities for regional water conservation and water use efficiency (including conveyance system improvements and irrigation district modernization), offer the prospect of near-term successes that could lead to further collaboration.

’08 JULY

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AN INTRODUCTION